International CLIMATE CHANGE ADAPTATION Initiative

Pacific Climate Change Science Program

End of Program Report

July 2009–December 2011

Australian AID

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Executive Summary

The International Climate Change Adaptation Initiative (ICCAI) is a five-year investment of $328.2 million by Australia to meet high priority climate adaptation needs in vulnerable countries in the Asia-Pacific region. There are four components to the ICCAI:

- Improved science and understanding;
- Strategic planning and vulnerability assessment;
- Implementing, financing and coordinating adaptation measures; and
- Multilateral support.

The Pacific Climate Change Science Program (PCCSP) was the primary input to the first component and will inform the other components. This $20 million program ran from July 2009 to December 2011. The Manager was Gillian Cambers. The three objectives of the PCCSP were to:

- Conduct a comprehensive climate change science research program aimed at providing in-depth information about past, present and future climate in 15 partner countries;
- Build the capacity of partner country scientific organisations, where feasible, to undertake scientific research to support the provision of this information; and
- Disseminate the information to partner countries and other stakeholders.

1. Provision of scientific information

The PCCSP was designed to address major gaps in climate change science, including understanding the drivers of climate variability, analysis of observed trends, country-specific climate projections, sea-level rise and ocean acidification. The main findings of the PCCSP research were documented in a 530 page peer-reviewed report *Climate Change in the Pacific: Scientific Assessment and New Research, Volume 1: Regional Overview; Volume 2 Country Reports*. This was published in hard copy and online in November 2011. Country-specific brochures were also published.

In addition, at the conclusion of the Program 26 peer-reviewed journal papers and four book chapters were published or in press, five papers were submitted to journals and 23 papers were in preparation.

Key findings

- The climate of the 15 partner countries in the western tropical Pacific is strongly influenced by one or more of the following features: the South Pacific Convergence Zone, the West Pacific Monsoon, and the Inter-Tropical Convergence Zone;
- Mean temperatures in the region have increased by 0.08 to 0.20°C/decade since 1960. Sea level in the region has risen by 2 to 10 mm/year from 1993-2009, with significant year-to-year variability. The global average rate of rise over the same period is 3.2 mm/year. Rainfall data since 1960 show large interannual variability due to such factors as the El Niño-Southern Oscillation, and large decadal variability due to the Interdecadal Pacific Oscillation. There has been no significant change in tropical cyclone frequency or intensity since 1981 (the satellite era);
- The future is expected to be warmer with more extremely hot days and warm nights, a general increase in annual mean rainfall and the number of heavy rain days, fewer droughts and tropical cyclones, more sea-level rise and more ocean acidification.

2. Capacity building

Ongoing engagement with the partner countries and regional organisations was an important part of capacity building under the PCCSP. Direct engagement took place during in-country visits and regional workshops, with frequent remote engagement via e-mail and telephone. Strong relationships were developed with key contacts.

Over 500 people were reached through five climate change science workshops, and training activities across all 15 partner countries.

Four tools were developed

1. The Pacific Climate Change Data Portal provides access to historical climate trends and basic climate information from more than 90 individual observation sites across the Pacific Islands and East Timor;
2. The Pacific Tropical Cyclone Data Portal provides access to detailed information and data on historical tropical cyclones for the Southern Hemisphere;
3. The Tropical Cyclone Wind Risk Model estimates the wind hazard from tropical cyclones;
4. The *Pacific Climate Futures* web-tool provides national and some sub-national projections. Across all 15 countries, over 350 people were trained in the Basic interface, and over 100 people were trained in the Intermediate and Advanced interfaces. Over 95% of participants who completed the Intermediate and Advanced training felt confident using the tool to provide projections to stakeholders, e.g.

"Knowing how to use Climate Futures is a big plus for us as advisors to government's key policymakers on planning, development, infrastructure, agriculture and zoning" – Federated States of Micronesia

"PCCSP Climate Futures will help us to access and provide better scientific information need for Palau to plan for future climate change" - Palau

A database named CliDE (Climate Data for the Environment) was developed for the National Meteorological Service (NMS) in each country. It was successfully installed in 14 partner countries and 83 people were trained. Over 95% of the trainees reported feeling comfortable or very comfortable with operating the database. During the in-country visits, the PCCSP team organised climate science workshops that reached over 150 people. This significant capacity-building activity was well received, e.g.

"It is so vital because it assists to store important data and helps me to search for data needed from people. It has improved my knowledge on how to store and output data" – Kiribati

In 2011, three scientists from Samoa, Papua New Guinea and Fiji worked with PCCSP scientists for two to six weeks to build climate science research capacity. Participants were required to produce agreed outputs, ranging from presentations to colleagues at the Bureau of Meteorology and CSIRO, to co-authored papers and oral presentations to be given at international conferences. Feedback was very positive, e.g.

"I can say with great confidence that the attachment has greatly enhanced my professional career development. Even though I enjoyed all the aspect of the attachment, the actual analysis of the data and conducting statistical analysis was the one that stood out for me personally. The benefit of working with respected Bureau scientists and creating that bond and understanding was a huge boost for my future work as far as networking is concerned" – Papua New Guinea National Weather Service

3. Information dissemination

At least 219 media items were published or broadcast as a result of the PCCSP activities. The focus of these falls into three broad categories: media as result of the two launches of *Climate Change in the Pacific* (154), the Greenhouse 2011 conference (24) and in-country visits (at least 41).

The report *Climate Change in the Pacific* was launched in Australia on 25 November 2011. On 6 December 2011, the report was highlighted again at a joint Australian Government / Secretariat of the Pacific Environment Programme (SPREP) event at the 17th Conference of the Parties (COP17) to the United Nations Framework Convention on Climate Change (UNFCCC) in Durban, South Africa. See www.pacificclimatechangescience.org

The PCCSP-sponsored partner country participants at the Greenhouse 2011 conference were offered the opportunity to undertake an interview to camera. Many of the participants found this an excellent learning opportunity in building their communication skills. Some of these interviews were used to produce a short video that was played during the COP17 side-event.

In response to the need to provide scientific information to different audiences, a series of brochure products were developed over the course of the PCCSP. This included two regional brochures and 15 individual brochures summarising the current and future climate of each partner country. In-country launches of the brochures were held in Kiribati and Samoa and the brochures were launched alongside the report in Vanuatu in November 2011. The country brochures were very well-received.

"Thanks so much to the team for your assistance throughout the years in preparing this, it is a very excellent piece of work and good to use Nauru for awareness purposes" – Nauru

"There were some positive feedback from people from different sectors – they find the information very useful, ideal for sector planning. A Land Management Officer of MNRE thought it was an excellent publication. It was one of the most popular brochure on the day since we have about a few left at the end of the day from the 100 we received. So we might need some more in future. We like to thank you for the support extended to us thus far" - Samoa

4. The way forward

A gaps and needs analysis of climate change science in the region was conducted with partner countries and regional organisations in 2010. The top seven priorities are:

- Broader communication of climate change science to partner country stakeholders;
- Further capacity building and education;
- Reducing uncertainty in atmospheric and oceanic projections;
- Robust attribution of climate change to natural and/or anthropogenic factors;
- Updated regional and country specific projections for 2020 to 2100 and beyond;
- More detailed projections for extreme events; and
- Detailed projections for selected economic sectors and regions.

Addressing each of these has been built into the new Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) program, which runs from July 2011 to June 2013.

List of Abbreviations

AusAID
Australian Agency for International Development

BoM
Bureau of Meteorology

CAWCR
Centre for Australian Weather and Climate Research

CCAM
Conformal-Cubic Atmospheric Model

CCiP
Climate Change in the Pacific

CDMS
Climate data management system

CliDE
Climate Data for the Environment

COP
Conference of Parties to the United Nations Framework Convention on Climate Change

CSIRO
Commonwealth Scientific and Industrial Research Organisation

DCCEE
Department of Climate Change and Energy Efficiency

ENSO
El Niño-Southern Oscillation

ERA
European Centre for Medium-range Weather Forecasts Reanalysis

GA
Geoscience Australia

GCM
Global Climate Model

GCOS
Global Climate Observing System

ICCAI
International Climate Change Adaptation Initiative

IPCC
Intergovernmental Panel on Climate Change

IPCC AR4
Intergovernmental Panel on Climate Change Fourth Assessment Report

IPCC AR5
Intergovernmental Panel on Climate Change Fifth Assessment Report

ITCZ
Inter-Tropical Convergence Zone

LSE
Large Scale Environment

MIT
Massachusetts Institute of Technology

MSLP
Mean sea level pressure

NCEP
National Centre for Environmental Prediction

NIWA
National Institute of Water and Atmospheric Research (New Zealand)

NMS
National Meteorological Service

NMHS
National Meteorological and Hydrological Service

NOAA
National Oceanic and Atmospheric Administration (USA)

PACC
Pacific Adaptation to Climate Change Project

PASAP
Pacific Adaptation Strategy and Assistance Program

PCCSP
Pacific Climate Change Science Program

SOI
Southern Oscillation Index

SPC
Secretariat of the Pacific Community

SPCZ
South Pacific Convergence Zone

SOPAC
Pacific Islands Applied Geoscience Commission

SPREP
Secretariat of the Pacific Regional Environment Programme

SST
Sea surface temperature

TCLV
Tropical cyclone-like vortex

TCRM
Tropical Cyclone Risk Model

USP
University of the South Pacific

WMO
World Meteorological Organization

WPM
West Pacific Monsoon

1. Introduction

The Pacific Climate Change Science Program (PCCSP) was developed to assist decision makers and planners in 14 Pacific island countries and East Timor to understand better how their climate and oceans have changed and how they may change in the future. The Program was set up to deliver early results in priority knowledge areas while providing the base upon which longer-term climate change science outcomes could be delivered. The $20 million PCCSP, a part of the International Climate Change Adaptation Initiative (ICCAI), ran from July 2009 to December 2011 (although some activities started earlier than this date). The PCCSP is being followed by the Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) Program, which commenced in July 2011 - the two programs ran in parallel during the six month period July-December 2011. This report covers the outcomes of the PCCSP between 2009 and 2011.

1.1 International Climate Change Adaptation Initiative

The ICCAI is a five-year, $328.2 million investment by Australia, to meet high priority climate adaptation needs in vulnerable countries in the Asia-Pacific region. The focus is on Pacific island countries and East Timor, however, targeted policy and technical assistance will also be available for other countries in the Asia-Pacific region.

The ICCAI is jointly managed by the Australian Agency for International Development (AusAID) and the Department of Climate Change and Energy Efficiency (DCCEE). The objectives of the ICCAI are to:

- Establish a sound policy, scientific and analytical basis for long-term Australian action to help partner countries adapt to the impacts of climate change;
- Increase understanding in partner countries of the impacts of climate change on their natural and socio-economic systems;
- Enhance partner country capacity to assess key climate vulnerabilities and risks, formulate appropriate adaptation strategies and plans, and mainstream adaptation into decision making; and
- Identify and finance priority adaptation measures that can immediately increase the resilience of partner countries to the impacts of climate change.

There are four components to the ICCAI:

- Improved science and understanding;
- Strategic planning and vulnerability assessment;
- Implementing, financing and coordinating adaptation measures; and
- Multilateral support.

The PCCSP was the primary input to the first component and will inform the other components. The Pacific Adaptation Strategy Assistance Program (PASAP) was the primary input to the second component.

1.2 Pacific Climate Change Science Program

1.2.1 Vision statement

The PCCSP is a partnership between Australian science agencies and Pacific island countries and East Timor, carried out in collaboration with Pacific regional organisations, with the objective being to conduct a comprehensive climate change science research program to provide better information about the likely impacts of climate change to stakeholders in participating countries.

1.2.2 Objectives

The objectives of the PCCSP were to:

- Provide meteorological, climatological and oceanographic (physical and chemical) information, particularly in areas where there are identified gaps in partner country knowledge;
- Build the capacity of partner country scientific organisations, where feasible, to undertake scientific research to support the provision of this information; and
- Disseminate the information to partner countries and other stakeholders.

1.2.3 Partner countries

The 15 PCCSP partner countries are:

- Cook Islands
- East Timor
- Federated States of Micronesia
- Fiji
- Kiribati
- Marshall Islands
- Nauru
- Niue
- Palau
- Papua New Guinea
- Samoa
- Solomon Islands
- Tonga
- Tuvalu
- Vanuatu

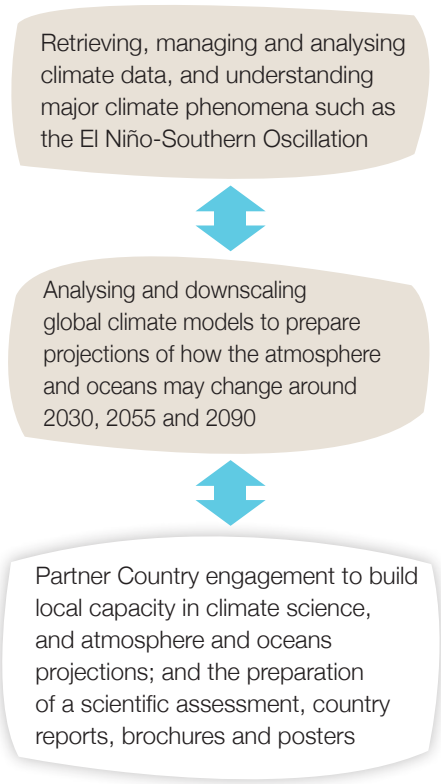
1.2.4 Program components

The PCCSP consists of five components, four of which cover research, and the fifth focuses on science information synthesis and communication:

- Component 1: Current and recent climate;
- Component 2: Regional drivers;
- Component 3: Climate change projections;
- Component 4: Oceans and sea-level rise; and
- Component 5: Science information synthesis and communication.

The components interact with each other and involve research, training and capacity building, and information sharing. The schematic on the next page shows a framework for how the components work together towards producing the final outputs.

Framework for the Pacific Climate Change Science Program:



1.2.5 Management framework

The PCCSP Management Framework was a three-tiered structure comprising the ICCAI Senior Officials Group, PCCSP Management Committee and the Project Implementation Team.

The ICCAI Senior Officials Group comprised the First Assistant Secretary Adaptation and Land Management (DCCEE), and the Assistant Director General Sustainable Development Group (AusAID). For the purposes of managing the PCCSP, the ICCAI Senior Officials Group was joined by the Director of the Centre for Australian Weather and Climate Research (CAWCR), the Director of the Commonwealth Scientific and Industrial Research Organisation's (CSIRO) Climate Adaptation Flagship and the Deputy Director (Research) of the Bureau of Meteorology (BoM). Operating by consensus, these five members provided direction to the PCCSP Management Committee on matters relating to the management, implementation and review of the PCCSP. Two meetings of the Senior Officials Group were held during the course of the PCCSP.

A PCCSP Management Committee, comprising the Director of the Pacific Adaptation Team (DCCEE), the Director Climate Resilience and Water Section (AusAID), and one representative each from CSIRO and the Bureau of Meteorology, appointed by the Director of CSIRO's Climate Adaptation Flagship and the Deputy Director (Research) of BoM respectively, were responsible for oversight and administration of the PCCSP. The PCCSP Program Manager was an ex officio member of this Committee. Terms of reference were approved for the PCCSP Management Committee. The PCCSP Management Committee met at approximately quarterly intervals between July 2009 and December 2010; this was reduced to semi-annually in 2011.

Implementation of the PCCSP was undertaken by the Project Implementation Team. This consisted of the five Component Leaders and was chaired by the Program Manager, who was also leader of Component 5. The Program Manager reported to the PCCSP Management Committee. Terms of reference prepared for the Project Implementation Team were approved by the PCCSP Management Committee. The Project Implementation Team met monthly between its inception in November 2009 and December 2011.

2. Addressing the Program's Objectives

This section discusses how the Program addressed the three objectives: (a) filling identified scientific gaps in the existing knowledge base; (b) building capacity of partner countries in climate change science; and (c) disseminating the information.

2.1 Provision of scientific information

The PCCSP was designed to address the following major gaps in climate change science:

- Management of climate data and analysis of data trends;
- Extreme events, including tropical cyclones;
- Understanding of large-scale climate features in the Pacific region, including the main driver of climate variability – the El Niño-Southern Oscillation (ENSO);
- Climate projections for the region and for specific countries; and
- Understanding of ocean processes and how they may change in the future under global warming, especially sea-level rise and ocean acidification.

Within the time frame of two and a half years, the PCCSP made significant progress in filling these gaps. As of 31 December 2011, 26 peer-reviewed journal papers and three book chapters had been published or were in press, five papers had been submitted and 23 were in preparation. The complete list is presented in Appendix1. The main findings of the PCCSP research were included in the 530 page peer reviewed report *Climate Change in the Pacific: Scientific Assessment and New Research, Volume 1: Regional Overview; Volume 2 Country Reports*. This was published in hard copy and online in November 2011.

The PCCSP consisted of four research components including 16 projects (see Table 1).

Table 1: List of Research Projects

Component 1
Current and recent climate

1.1 Rehabilitation of meteorological data

1.2 Data rescue and data management including CliDE

1.3 Improving the understanding of tropical cyclone climatology

Component 2
Regional drivers of climate variability

2.1 El Niño-Southern Oscillation (ENSO)

2.2 South Pacific Convergence Zone

2.3 West Pacific Monsoon and the Inter-tropical Convergence Zone

Component 3
Climate projections

3.1 Global climate model projections

3.2 Tropical cyclones

3.3 Dynamical downscaling

3.4 Additional downscaling

3.5 Statistical downscaling

3.6 Tailored projections

Component 4
Oceans and sea-level rise

4.1 ENSO variability and climate change

4.2 Sea level projections for the Pacific Islands' region

4.3 Ocean acidification

4.4 Effects of climate variability and climate change on extreme sea level events

The following sections, 2.1.1 to 2.1.5, describe how these projects contributed to addressing the major gaps. Appendix 2 presents a summary of the scientific methodology and outcomes of each project. Section 2.1.6 describes the major gaps still to be addressed, and these have been incorporated into the design of the follow-up Pacific-Australia Climate Change Science and Adaptation (PACCSAP) program.

2.1.1 Management of climate data and analysis of data

Climatic data were generously provided by the National Meteorological Service from each partner country. These data were quality-checked at a workshop in Darwin. Adjustments were made to correct for any spurious records – this is called homogenization. The updated homogeneous records indicate that mean temperatures have increased at all available Pacific island stations over 1960-2010, with rates ranging from +0.08 to +0.20ºC/decade. The strongest warming trends are found in Papua New Guinea and French Polynesia. None of the updated homogeneous records show cooling over the past 70, 50 or 30 years. Trends in maximum and minimum temperatures are very similar to those of mean temperature at most stations.

The updated rainfall series clearly show the large interannual variability experienced in the tropical Pacific which is linked to such factors as the El Niño-Southern Oscillation, and large decadal variability due to the Interdecadal Pacific Oscillation. This variability is large compared with the magnitude of long-term rainfall trends, making them less spatially coherent than those for temperature. Trends in total annual rainfall for the longest available rainfall records indicate a general increase in rainfall totals north-east of the South Pacific Convergence Zone over the past 50 years, with mainly declines to the south-west of the South Pacific Convergence Zone, and north of the Inter-Tropical Convergence Zone just west of the International Date Line. This pattern of change is generally reflected in both wet and dry seasons. Analysis of the last two decades reveals a marked reversal of earlier trends, consistent with a shift of the South Pacific Convergence Zone back to its climatological position since 1990 with increase in the south-west Pacific and decreases to the north-east of the South Pacific Convergence Zone. Unlike changes in temperature, which are dominated by background global warming, the lack of a sustained trend in rainfall suggests that Pacific rainfall patterns continue to be strongly influenced by natural climate variability.

As part of the research a Pacific Climate Change Data Portal was developed. This user-friendly web-tool provides access to historical climate trends and basic climate information from more than 90 individual observation sites across the Pacific Islands and East Timor. It is freely available for anyone to explore climate trends at www.bom.gov.au/climate/pccsp.

A database management system using open source software was developed. The database, named CliDE (Climate Data for the Environment), was developed after significant research into the current operating systems being used by the countries and with the collaboration and input of the partner countries' NMS. It was successfully installed in 14 partner countries and 83 people were trained. It will be installed in Nauru under the PACCSAP program. CliDE has greatly improved the usability and accessibility of NMS data archives. It allows them to improve their services and undertake more climate research in future years through significant capacity building in data management including reducing risk in loss/destruction of paper records.

2.1.2 Extreme events

Tropical cyclones are among the most destructive natural hazards, affecting millions of people around the world each year. There is some uncertainty as to how climate change influences tropical cyclones as detecting trends in tropical cyclones requires long, accurate data records. Changes in recording practices can influence the analysis of tropical cyclone trends. For example, since the early 1970s there has been an increase in available data with the introduction of satellites. A rigorous analysis of the data was undertaken by the PCCSP.

A tropical cyclone archive for the Southern Hemisphere has been revised and now consists of tropical cyclone best track data for the "satellite era" i.e. the tropical cyclone seasons from 1969/70 to 2009/10. Analyses

have been undertaken to understand the variability in tropical cyclone occurrences across the Southern Hemisphere (south of the equator, 30°E to 120°W). Much of the variability of tropical cyclones can be understood (and even predicted in advance) using broad-scale indices which describe the El Niño-Southern Oscillation (ENSO) phenomenon. For the 1981/82 to 2006/07 tropical cyclone seasons, there are no apparent trends in the total numbers of tropical cyclones, nor in numbers of 970 hPa tropical cyclones (such tropical cyclones being called severe in the Southern Hemisphere). The quality of best track tropical cyclone data in the Southern Hemisphere was examined in detail and it was concluded that issues with the data homogeneity limit our ability at the present time to answer the important question of how tropical cyclone activity in the Southern Hemisphere is changing and its possible relationship to global climate change more generally.

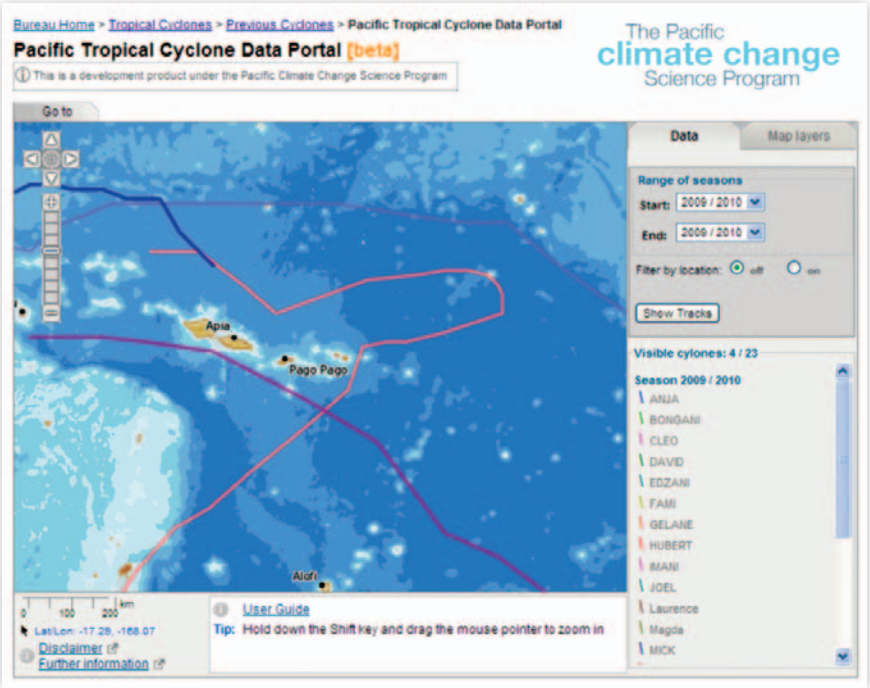
To provide access to detailed information and data on historical tropical cyclones for the Southern Hemisphere, a specialised website was developed using an OpenLayers platform. The Pacific Tropical Cyclone Data Portal can be used to plot tracks of cyclones in the South Pacific between 1969 and 2010, allowing users to see the characteristics and paths of past tropical cyclone events. Meteorologists and stakeholders can use this tool to analyse the tracks of historical tropical cyclones and relate them to the impact on lives and infrastructure recorded on the ground. The Pacific Tropical Cyclone Data Portal is freely available at www.bom.gov.au/cyclone/history/tracks.

The Tropical Cyclone Wind Risk Model estimates the wind hazard from tropical cyclones. It uses a statistical model to generate thousands of years' worth of storms that are similar to the observed cyclone track data and a parametric wind field and boundary layer model to simulate the storm winds. It also incorporates downscaled climate model projections.

Results from three different methods used to analyse the global climate models showed that the methods are able to reproduce the climatology of tropical cyclones for the current climate. There is, however, considerable variation between the three techniques in the projected changes. Projections based upon these different modelling systems and analysis techniques show that tropical cyclone frequency in the PCCSP region is likely to decrease by the late 21st century. There is a moderate level of confidence in this projection, with little consistency found in the magnitude of the projected changes between either the models or the analysis methods. Most CCAM simulations project an increase in the proportion of the most severe storms in the southwest Pacific and a poleward movement in the latitude at which maximum intensity occurs.

Storm surges cause elevated sea levels which can result in flooding and coastal erosion. As sea level rises, the impact of extreme sea level events, due to storm surges and high tides, will become more severe. A review of literature relevant for sea level extremes was carried out and published (Walsh et al, 2012). An analysis of tide gauge data was undertaken to develop the extreme sea level annual climatologies. Results showed that tidal extremes clustered around either the solstices or the equinoxes were fairly uniform throughout the year due to the differences in the dominant tidal characteristics at each location. The analysis also showed the relationship between higher than normal sea levels and the La Niña/El Niño cycle.

To investigate storm surges along the entire Fiji coastline, a synthetic tropical cyclone and storm surge modelling study was undertaken. Tropical cyclones that have affected Fiji were characterised in terms of intensity, track and frequency for all years and La Niña and El Niño years. A population of 1000 plausible cyclones for that region were sampled. The synthetic cyclone modelling showed that the north-western coastlines of Viti Levu and Vanua Levu experienced the highest storm surges because they face the most common direction of approach for tropical cyclones. The one in one-hundred year storm surge heights on northwest coasts were found to be around twice the values at locations in the southwest. Due to differences in tropical cyclone paths and frequencies, the northern island was slightly more at risk of storm surges during El Niño years.



2.1.3 Understanding large-scale climate features

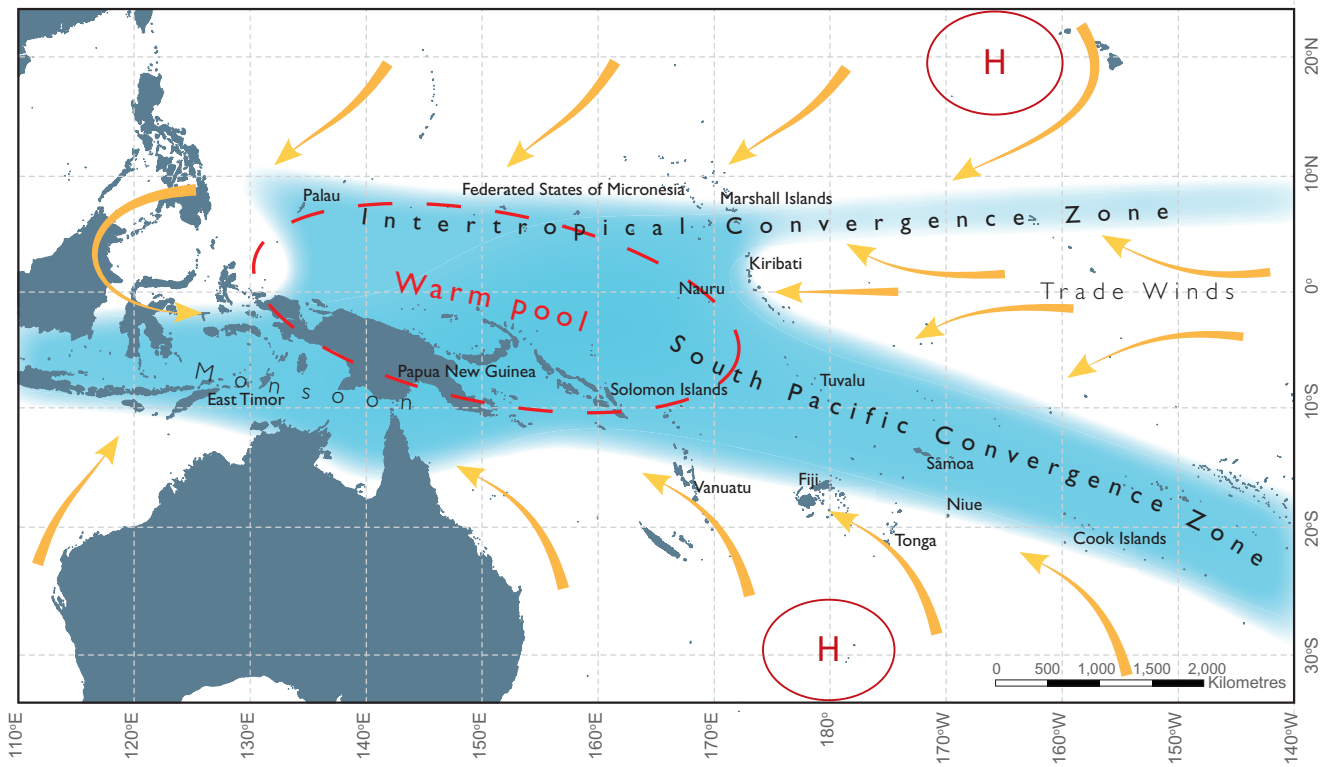
The climates of partner countries are strongly influenced by one or more of the following features of the climate: the South Pacific Convergence Zone (SPCZ), the West Pacific Monsoon (WPM), the Inter-Tropical Convergence Zone (ITCZ) and El Niño-Southern Oscillation (ENSO). These features can 'drive' rainfall, winds, tropical cyclone tracks, ocean currents, nutrients and many other aspects of the environment. Despite their fundamental importance to the region, there are still major deficiencies in understanding the properties and impacts of these climate features.

ENSO is associated with large rainfall variations in many partner countries. Countries east of 160ºE and close to the equator experience above-average rainfall during an El Niño, while other countries experience drier than normal conditions. CMIP3 models vary in their ability to reproduce the strength and frequency of ENSO events. Many models may not simulate the correct changes in rainfall during El Niño and La Niña events for some partner countries due to errors in how they simulate ENSO. Twenty-first century interannual variability in the region will continue to be largely driven by ENSO. Unfortunately, climate models do not provide consistent projections of changes in the frequency, intensity and patterns of future El Niño and La Niña events. As the climate changes, however, some aspects of the climate experienced in some regions during El Niño and La Niña events may change (e.g. future El Niño events will tend to be warmer than El Niño events experienced in the past).

The PCCSP organized the first ever international conference dedicated to examination of the SPCZ in observations and in climate model simulations of the 20th and 21st centuries. This was held in Samoa in August 2010. The PCCSP research documented the main features of the SPCZ and both its seasonal and interannual variability, developed methods to characterise major features of SPCZ (e.g. latitude and spatial orientation) and examined changes in the SPCZ under global warming.

Evaluation of 24 global climate models showed that whilst 20 models simulate a distinct SPCZ, four models incorrectly merge the ITCZ and SPCZ rainfall. The majority of models simulate an SPCZ with an overly east-west orientation, rather than extending in a diagonal band into the southeast Pacific as observed. The response of the SPCZ to climate change was examined using simulations from 16 climate models under the A2 (high) emissions scenario. The majority of models simulate a future increase in the area of the SPCZ and in mean and maximum precipitation within the SPCZ, consistent with increased moisture convergence in a warmer climate.

The impact of the ITCZ and the WPM on climate in the partner countries was documented. The year-to-year variability in the extent of the monsoon-affected region is significant, especially on the eastern edge, where it varies by more than 5000 km between maximum and minimum extent. The two most extreme maximum eastern extents of the monsoon domain occurred during the strong El Niño years of 1983/84 and 1997/98. The north-



The main climate features in the western tropical Pacific region.

south variability of the westerly wind domain is much less pronounced.

Seasonal and year-to-year variability in the position and intensity of the ITCZ can have significant impacts on low latitude Pacific nations due to its north-south narrowness and large rainfall gradients. As the mean seasonal shift of the ITCZ is only 2° of latitude in the central Pacific, even small shifts in overall location can result in large impacts. The latitude of the ITCZ varies from year-to-year. For example, during 1979-1999 the ITCZ tended to be approximately 3° closer to the equator during El Niño conditions than during La Niña conditions. Rainfall amounts in the ITCZ are also strongly influenced by ENSO.

Overall, with only a few exceptions, the CMIP3 climate models capture the major climatic features of the monsoon, including the seasonal reversal of the surface winds and the dominance of summer rainfall over winter rainfall. Similarly, climate models on average reproduce the seasonal cycle of ITCZ rainfall amounts reasonably well. Projections for the 21st century show a general tendency for an amplification of the seasonal cycle of rainfall in the West Pacific Monsoon region and in the ITCZ region.

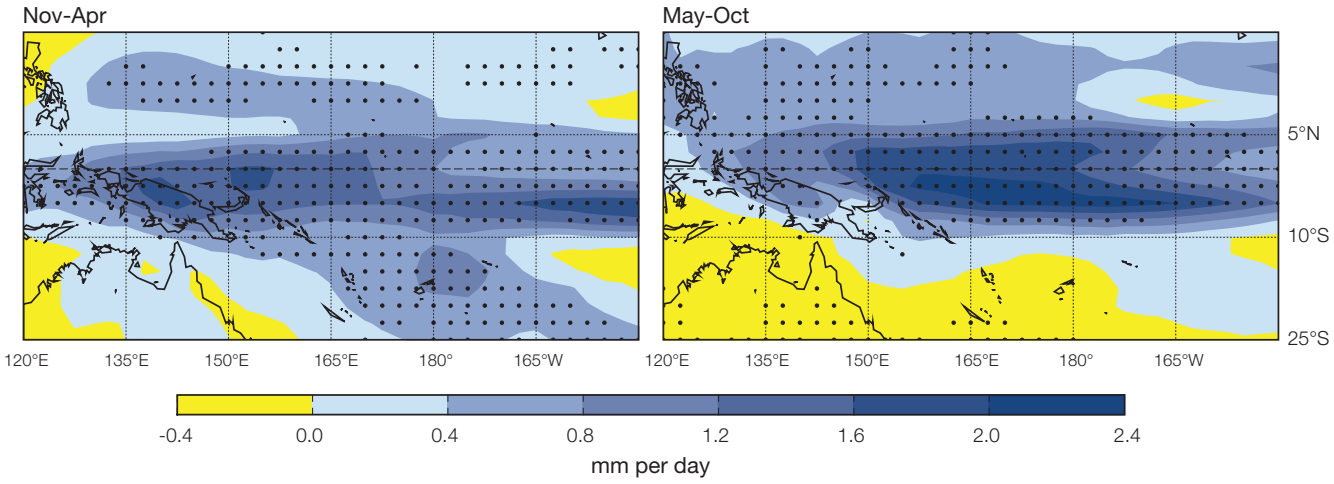
2.1.4 Climate projections

Prior to the work of the PCCSP, limited information was available on climate projections for the Pacific. The IPCC Fourth Assessment Report (AR4) provides annual and seasonal average temperature and rainfall projections for the whole Pacific divided into only two regions (north and south) and projections of global average sea-level. The PCCSP provided more detailed atmospheric and ocean projections for each partner country.

Twenty-four global climate models were evaluated by comparing the present-day climate simulations against historical observations, and 18 were considered suitable for projections. Projections were developed for three 20-year periods (centred on 2030, 2055 and 2090) and three emissions scenarios (low-B1, medium-A1B and high-A2). Projections were presented for the whole region and for individual partner countries. Higher temperatures are very likely with more extremely hot days and warm nights. Annual mean rainfall generally increases, and there is an increase in the number of heavy rain days (20-50 mm) and the intensity of extreme rainfall events (occurring once in 20 years). Surface wind speed decreases slightly in the equatorial and northern parts of the region, with small increases in the south. There are relatively small changes in humidity and solar radiation, generally with increasing humidity and decreasing solar radiation. Potential evapotranspiration is projected to increase except along the equator and over Papua New Guinea and the frequency of droughts is projected to generally decrease. Country-specific results are detailed in Volume 2 of *Climate Change in the Pacific: Scientific Assessment and New Research*.

Dynamical downscaling (using finer resolution climate models), combined with statistical downscaling for selected regions, was also undertaken to provide more detailed information.

The Conformal Cubic Atmospheric Model (CCAM) was used to provide 60 km downscaled projections for the PCCSP region. Six global climate models were selected for dynamical downscaling using the A2 (high) emissions scenario. The results from the CCAM 60 km downscaling are broadly consistent with those of the global climate models. However, some differences between the global climate model projections and the CCAM projections are noted, such as bands of rainfall decrease around latitudes 8°N and 8°S. Seven countries were chosen to downscale to 8 km resolution: East Timor, Papua New Guinea, Solomon



The 18-model average change in rainfall for 2080-2099, relative to 1980-1999, under the A2 (high) emissions scenario. Regions where at least 80% of models agree on the direction of change are stippled.

Islands, Vanuatu, Fiji, Samoa and the Federated States of Micronesia. The CCAM 8 km downscaled projections show regional-scale variations of the climate change signal, largely related to the topography of partner countries.

In collaboration with other international organisations, five additional regional climate models were used to provide 60 km downscaled projections. The main research finding was that although the various models used different dynamics, physics and model set-ups, the climate change signal was broadly similar.

A new methodology for statistical downscaling that provides improved forecast accuracy compared to other standard approaches was developed and validated. The methodology was applied to 17 climate stations in the Pacific to provide projected daily climate data for 2021-2040 as well as the corresponding base-period simulations (1981-2000). Projections were also prepared for the period 2046-2065 for 12 locations. The countries for which statistical downscaling was performed were Cook Islands, Federated States of Micronesia, Fiji, Marshall Islands, Samoa, Solomon Islands and Vanuatu. Climate data from other islands were of insufficient quality to produce reliable statistical downscaled projections. The results of the statistical downscaling generally supported the results from the global climate models and show a projected increase in average daily rainfall in most locations for most host models. Average maximum and minimum temperature are consistently projected to increase in all locations regardless of which global climate model predictors are used to drive the statistical downscaling.

The PCCSP applied a new approach called Climate Futures to deliver projection information to partner countries. This approach groups the projections from individual models to form a set of internally consistent climate futures, which is a more scientifically robust method than mixing projections from different models. The *Pacific Climate Futures* web-tool was developed in collaboration with the partner countries and involved extensive testing. The web-based tool is available at a basic, intermediate and advanced level. The Basic interface is freely available at www.pacificclimatefutures.net, while the Intermediate and Advanced interfaces are also freely available for those who have undergone training.

Pacific Climate Futures has been very well received by the partner countries as well as at the UNFCCC 17th Conference of the Parties in Durban, South Africa. Training has been provided in all 15 countries and, based on the training evaluations, almost half of those trained to Advanced level indicated they are now confident in their ability to produce tailored projections for impact assessments in their country. This is a very significant outcome as, for many participants, this was their first exposure to climate projections work. The PCCSP has succeeded in developing a tool that simplifies the communication of climate projections and provides the functionality needed by the impacts and adaptation communities in the PCCSP partner countries.

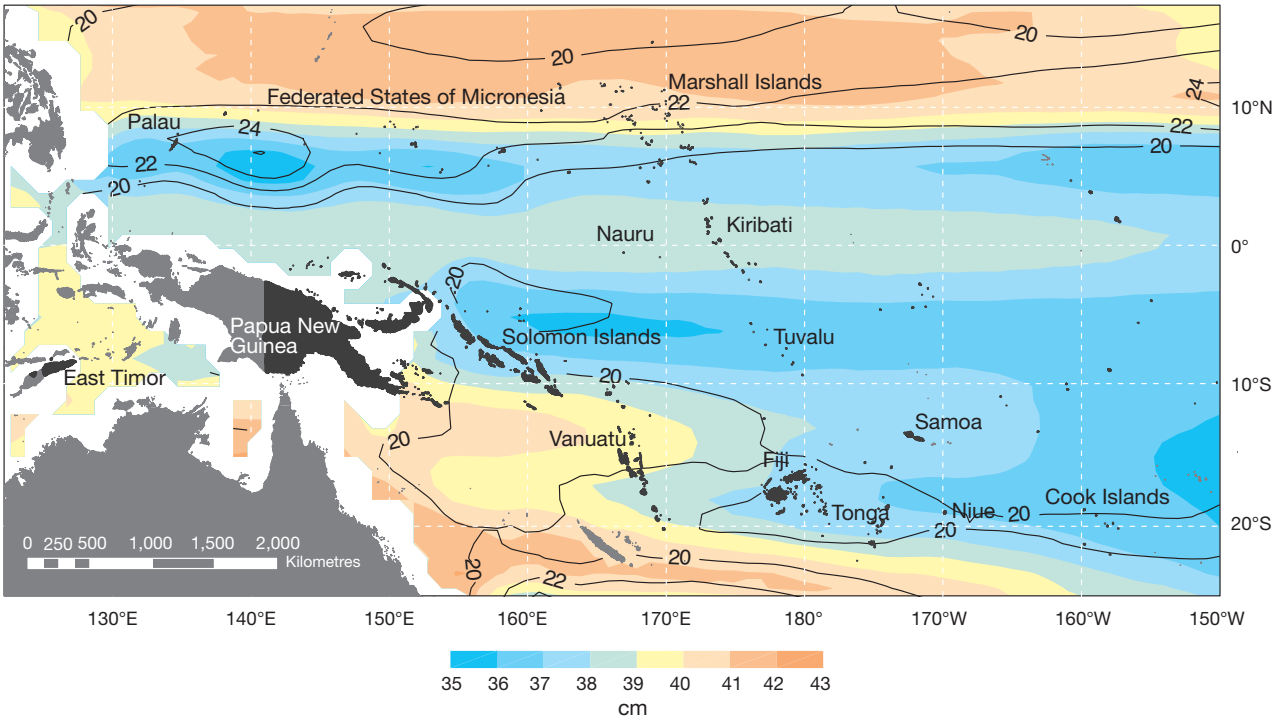
The PCCSP has provided advice on the most robust and up-to-date projections available for the development of AusAID's country-specific climate change profiles.

2.1.5 Ocean processes and changes

The atmosphere and the ocean are closely linked, so it is vital to understand the nature of the interaction and how it will change with global warming. Changes in the ocean will also directly affect biological systems including fisheries and coral reefs. The PCCSP worked with partner countries to understand how the increased heat entering the ocean will change ocean currents, salinity, temperatures and the supply of nutrients.

Work was undertaken showing how ocean temperature and salinity have changed over the past 60 years. Observational data sets of salinity were compiled and analysed for trends over the past 50 years. These showed a freshening trend in the western Pacific. Extensive work was undertaken to understand and analyse past changes in the oceans and atmosphere and how the global climate models perform. In particular, significant attention was given to addressing climate model drift, which is a spurious trend in global-mean climate that can occur in some models without any change in external forcing of the climate system. One model was rejected because the drift was considered excessive.

Many partner countries are already experiencing sea-level rise. The observed sea-level rise since 1972 can be well explained by ocean warming and glacier melt with additional contributions from the ice sheets and changes in terrestrial storage. Sea level in the region has risen by 2 to 10 mm/year from 1993-2009, which is up to three times the global average of 3.2 mm/year. Regional sea-level change can be significantly affected by low-frequency (interannual to interdecadal) modes of climate variability. The PCCSP prepared projections for the region based primarily on the IPCC Fourth Assessment Report. Model projections were compared with observational estimates where available, and model calculations were undertaken to determine how long it takes for a melting ice sheet signal to be experienced in the Pacific. The results showed that regional projections of sea-level rise in the PCCSP region are close to the global averaged rise for three different emissions scenarios and three different time periods. Projections for the period 2081-2100 for the A1B (medium) emissions scenario are shown in the figure on page 12. Ice sheet contributions are very uncertain at this stage.



Sea-level rise projections for the A1B (medium) emissions scenario for the average over 2081–2100 relative to 1981–2000 are indicated by the shading, with the estimated uncertainty in the projections indicated by the contours (in cm).

The ocean is a major sink for atmospheric carbon dioxide. It absorbs about one quarter of the carbon dioxide emissions resulting from human activities each year. This helps to slow the rate of atmospheric carbon dioxide increase but results in ocean acidification. This in turn decreases the capacity of reef building corals, calcareous algae and many other key species in tropical ecosystems to grow calcium carbonate skeletons and shells.

Historical data were compiled for the Pacific Island region and were used to calculate the aragonite saturation state (Ω) of the seawater. An offline carbonate chemistry model coupled to IPCC AR4 model projections was used to project changes in aragonite saturation state for the period 2010-2090. An ensemble of six models under high, medium and low emissions scenarios was used. Results showed the mean value of Ω in surface waters of the study region has declined from about 4.6 in pre-industrial times to present day values of about 3.7. Surface seawater Ω varies spatially and temporally. Some countries are surrounded by waters with Ω fluctuating seasonally between 3.5 and 3.9. Regionally, conditions that are considered marginal for supporting healthy reefs (Ω < 3.5) will occur in the Central Equatorial Pacific in the next few decades. The reef ecosystems in the region of the South Equatorial Current will be the last to experience these conditions. All reefs in the Pacific Island region are predicted to be exposed marginal growing conditions (Ω < 3.5) by about 2050, with the lowest values of Ω expected for the highest emissions scenario.

2.2 Building capacity of partner countries in climate change science

2.2.1 Process for engagement

With a Program involving more than 60 research scientists, and stakeholders in 15 partner countries, it was important to establish a clear method of engagement. PCCSP Focal Points were established in each country - for the most part, these were representatives from agencies charged with the environment portfolio. PCCSP Technical Representatives were also identified and these were generally from the NMS. Communication was usually directed to the Focal Point and copied to the Technical Representatives. For specific scientific and data requests, there was direct contact between PCCSP scientists and government officers. The communication process was endorsed by each country and worked well. Strong relationships were developed with key contacts.

Ongoing engagement with the partner countries and regional organisations was an important part of the capacity building under PCCSP. Direct engagement took place during in-country visits and regional workshops and at other times engagement was via e-mail and telephone. The countries were kept informed about significant milestones in the Program and their feedback was actively encouraged as PCCSP research continued and tools and products were produced. For example, partner country representatives provided feedback and input to the design of the *Pacific Climate Futures* web-based tool and CliDE, the climate database management system, and their input was also sought in the preparation of products such as the PCCSP brochures and the final publication *Climate Change in the Pacific: Scientific Assessment and New Research*.

Recognising that air travel contributes a significant amount of carbon dioxide into the atmosphere, the additional carbon generated by all PCCSP related air travel and events was offset through tree planting programs in Western Australia. Similar programs have not yet been identified in the partner countries.

Collaboration with regional organisations was also another major focus during the PCCSP. This was extremely important for building sustainability and regional ownership of the PCCSP. Important collaborative relationships were established with the Secretariat of the Pacific Community (SPC), Pacific Islands Applied Geoscience Commission (SPC-SOPAC), Secretariat of the Pacific Regional Environment Programme (SPREP), United Nations Development Programme (UNDP), University of Hawai'i, University of the South Pacific (USP), National Institute of Water and Atmospheric Research (NIWA), National Oceanic and Atmospheric Agency (NOAA) and Environment Canada. Table 2 provides some examples to illustrate the varied nature of the collaboration.

Within the framework of the ICCAI, the PCCSP has also collaborated directly with PASAP, e.g. in the implementation of the PCCSP Climate and Ocean Projections Workshop, held in Cairns, 22-26 March 2010. The PCCSP is represented on the PASAP Management Committee and this has improved connections between the two Programs, highlighted synergies and limitations, and led to modification of some PCCSP milestones so that the scientific findings could better inform adaptation planning work. Interim projections from the *Pacific Climate Futures* tool were provided to PASAP in May 2011.

Presentations on the PCCSP were made at several international events, e.g. the Pacific Climate Change Round Table held in the Marshall Islands, October 2009, and in Niue, 2011. More than 70 presentations on the PCCSP science were made by PCCSP scientists at regional and international conferences and workshops between July 2009 and June 2011.

Table 2: Collaboration with regional organisations

Organisation	Examples of collaboration
SPREP	• Joint regional workshop on 'Interim Climate Projections' held in Cairns, March 2010 • PCCSP presentations on 'Climate Projections' at SPREP-PACC regional workshop, held in Samoa, April 2010 • Involvement of SPREP in the PCCSP sessions at Greenhouse 2011, Cairns, April 2011 • Showcasing of PCCSP's main publication *Climate Change in the Pacific: Scientific Assessment and New Research* at a SPREP- sponsored side event at COP17 in Durban, South Africa, December 2011
USP	• Collaboration with the USP Conference on 'Future challenges, ancient solutions' held in Suva, Fiji, December 2010: PCCSP sponsorship and presentations • Presentation of the PCCSP interim results at a Training & Capacity Building Regional Workshop on 'Climate Variability and Change in PICs: Impacts, Vulnerability and Adaptation, November 2010' • Attachment of USP graduate student to PCCSP to undertake joint work on ocean acidification
NIWA	• Joint input to the Samoa Climate Early Warning System with the establishment of CliDE, November 2010 • Collaboration with further applications of CliDE and development of a CliDEsc application that will be led by NIWA, mid 2011 onwards

Developing fair and secure data sharing arrangements between PCCSP scientists and partner countries has been a key priority that was first discussed at the PCCSP Regional Workshop held in Vanuatu, October 2009. As a result of those discussions, an Interim Agreement on Data Security Arrangements was prepared and sent to partner countries in November 2009. This was followed by a Memorandum of Understanding for longer-term data sharing arrangements that was sent to partner countries in March 2011.

2.2.2 Regional workshops, conferences and events

Five PCCSP regional workshops have been conducted:

- PCCSP Regional Workshop, Vanuatu, 12-16 October 2009;
- PCCSP Climate and Ocean Projections Workshop, Cairns, 22-26 March 2010;
- PCCSP Climate Data, Variability and Change Research and Training Workshop, Darwin, 31 May – 9 June 2010.
- International Scientific Research Workshop on the South Pacific Convergence Zone, Samoa, 23-26 August 2010; and
- PCCSP Climate Futures Workshop, 31 March – 1 April 2011, Cairns and partner country involvement in the Greenhouse 2011 conference, Cairns 4-8 April 2011.

The workshop in Vanuatu was attended by 35 participants, of which 16 were from PCCSP's partner countries' NMS. Representatives from DCCEE, SPC and the World Meteorological Organization (WMO) also attended. The workshop achieved its three main objectives:

- Partner country representatives described their country's current climate, how their climate is changing, climate data management status, and climate change issues;

- PCCSP scientists introduced the detailed components of the PCCSP and obtained feedback; and
- Progress was made on creating a sense of ownership of the PCCSP among partner countries so as to encourage their active and ongoing participation.

The March 2010 workshop in Cairns was conducted in partnership with SPREP and PASAP. This five-day workshop was attended by a total of 63 participants, of which 25 were from the PCCSP's 15 partner countries. The majority of the partner country representatives came from their country's administration engaged in national planning, resource allocation, and/or mainstreaming of climate change and environment issues across government. Representatives from AusAID, DCCEE, NIWA, SPC and SPREP also attended the meeting. The first four days of the program were devoted to PCCSP and the fifth day to PASAP. The workshop achieved its three main objectives:

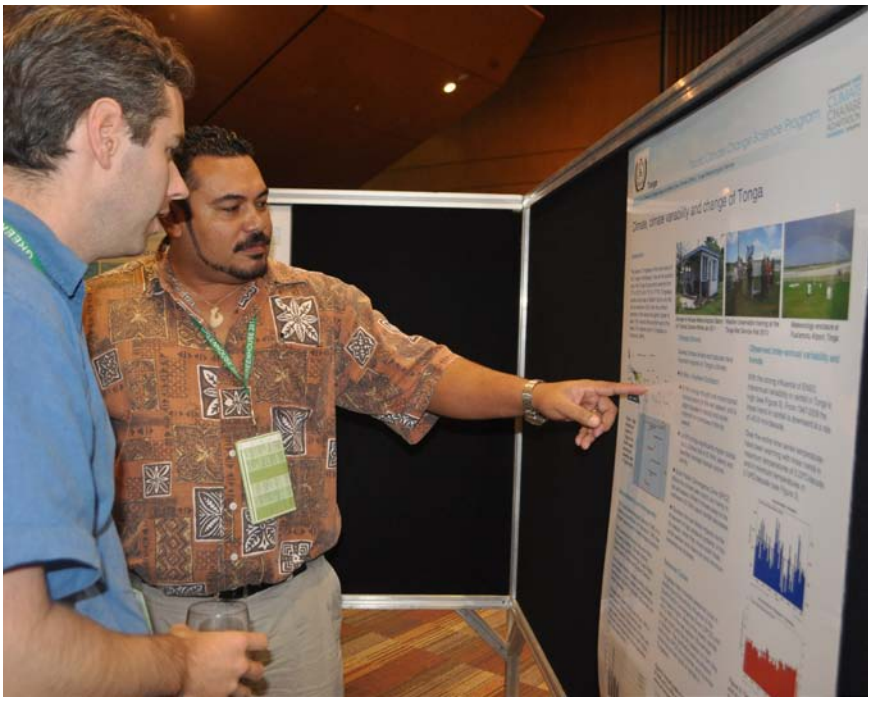
- Participants' knowledge of observed climate trends, drivers of climate variability, global climate model applications and their reliability, and the benefits of downscaling was enhanced;
- Interim projections for climate and ocean changes across the whole PCCSP region were presented and feedback received; and
- The prototype of the *Pacific Climate Futures* software tool for creating national and some sub-national projections was tested and feedback received.

After the success of the workshop in Cairns, partners at SPREP invited the PCCSP to give a one-day presentation on climate and ocean projections at the Pacific Adaptation to Climate Change (PACC) Project Workshop held in Samoa from 10-14 April 2010. Three PCCSP scientists conducted the session and again there was considerable interest among the Pacific country representatives in the preliminary atmospheric and oceanic projection information that was presented.

The workshop in Darwin was attended by 54 participants, 29 of whom were from NMS and related agencies in all 15 partner countries. This workshop was also attended by representatives from DCCEE, Environment Canada, NOAA, NIWA and SPREP.

Pacific Climate Futures training in the Cook Islands.

Pacific Climate Futures training in Papua New Guinea.



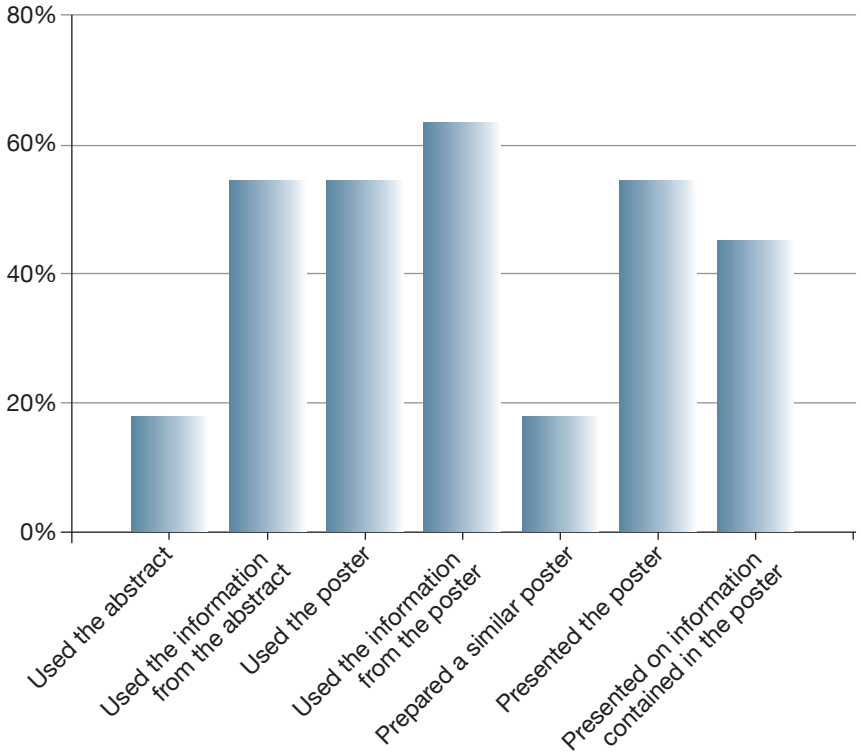
Greenhouse 2011: Poster presentation training.

The Darwin workshop program introduced concepts relating to climate data management, data quality control, trend analysis and correlation with climate driver indices. Participants were introduced to a newly designed climate database management system and two data analysis web portals, and feedback was obtained. Global climate models, and climate and ocean projections, were also introduced and the climate futures tool for country-specific projections was demonstrated. The highlight of the last three days of the workshop was the preparation of country-specific climate summaries, accompanied by PowerPoint presentations by each partner country. During the following months, partner countries and PCCSP scientists further developed these summaries to form the basis of part of the Country Reports in Volume 2 of *Climate Change in the Pacific* and the country brochures. The high standard of these summaries at Darwin was a clear indication of the benefits of the PCCSP's capacity building and training activities.

An international workshop on the SPCZ was held in Samoa from 24-26 August 2010. Thirty participants attended the workshop which brought the world's leading experts on the SPCZ together with representatives from the NMS in those partner countries impacted by the SPCZ. This workshop was the first international meeting on the SPCZ and was endorsed by World Climate Research Programme on Climate Variability and Predictability International Pacific Implementation Panel. The workshop was sponsored by the PCCSP and several other international organisations. The objectives of the workshop were to advance the understanding of the structure, physics, properties and impact of the SPCZ together with its simulation. The workshop was extremely successful and achieved its objectives.

In April 2011, a two-day workshop on the *Pacific Climate Futures* web-tool was combined with participation at the Greenhouse 2011 conference. One participant from each PCCSP partner country and the climate change focal point from SPREP, were invited to attend the Greenhouse 2011 conference with the support of the PCCSP. Thirteen Pacific island representatives attended, plus two Pacific island journalists.

Utilisation of PCCSP resources and skills after participating in regional workshops



The partner country representatives wrote and submitted abstracts for a scientific poster on the climate, climate variability and change of their country. The participants then presented these posters at two poster sessions during the conference. Three participants also submitted abstracts for verbal presentations which they presented during the Pacific sessions at the conference.

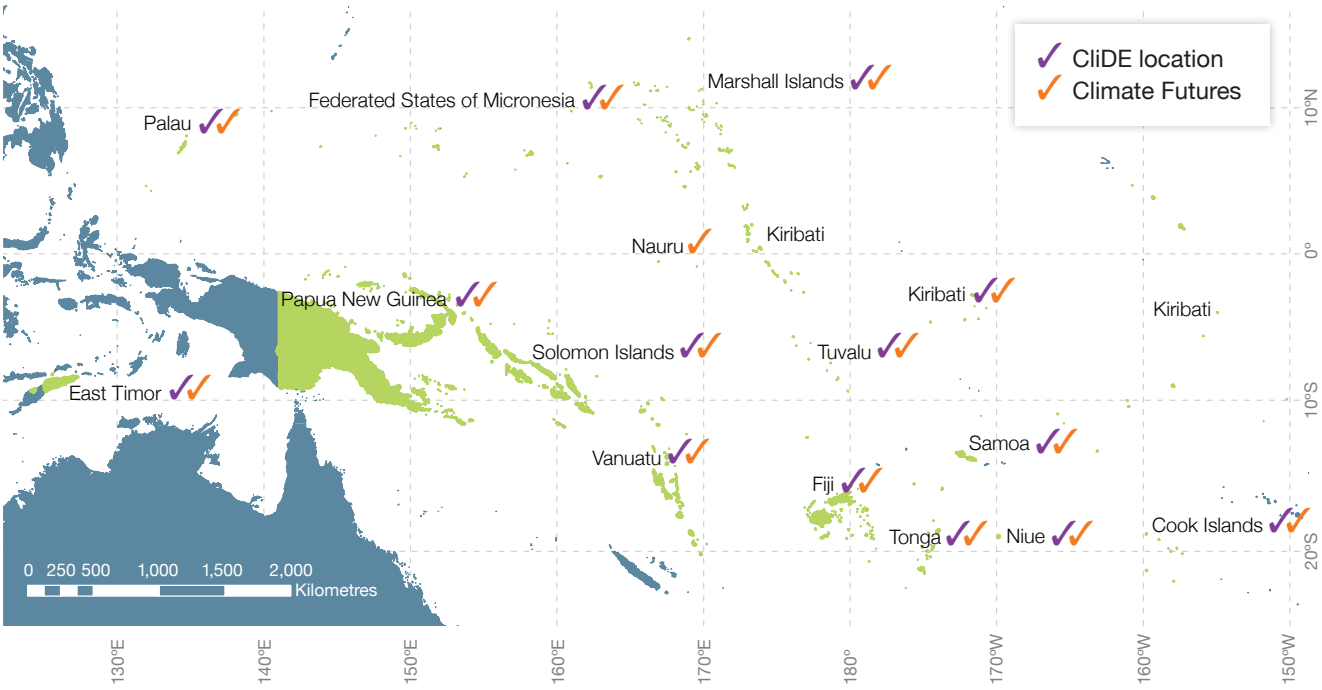
Overall this program provided an opportunity for representatives from the PCCSP's 15 partner countries to work with PCCSP scientists to build capacity in communicating climate science through the development of their poster. It also encouraged participants to liaise, collaborate and further their understanding of climate science by taking part in a conference attended by internationally renowned climate scientists.

Follow-up with the participants after the Greenhouse 2011 conference showed that resources and skills fostered under this (and other) PCCSP capacity-building initiative continue to be utilised in partner countries beyond the point of their initial introduction.

2.2.3 In-country training

Towards the end of 2010, the focus of the PCCSP's capacity building turned from regional events to in-country visits for the purposes of installing CliDE and *Pacific Climate Futures* and providing training in their use, as well as communication of other PCCSP findings to partner countries.

CliDE was successfully installed in 14 PCCSP partner countries and the PCCSP trained 83 people in the tool. It will be installed in Nauru under the PACCSAP program. Over 95% of the trainees reported feeling comfortable or very comfortable with operating the database. During these visits, the PCCSP team organised climate science workshops that reached over 150 people. These visits assisted in bringing



In-country training visits for CliDE and *Pacific Climate Futures*.

climate change stakeholders in partner countries together. In particular they helped to promote the role of the NMS in managing and providing climate data that are vital to understanding climate change and to informing adaptation projects being undertaken by different sectors. CliDE was very well received:

"It is so vital because it assists to store important data and helps me to search for data needed from people. It has improved my knowledge on how to store and output data" – Kiribati

"For me, I am personally proud because it is for the first time to have such training" – East Timor

Pacific Climate Futures training was successfully provided by 37 scientific and coordination officers to a diverse range of stakeholders in 15 PCCSP partner countries, with over 350 people trained in the Basic interface and over 100 people trained in the Intermediate and Advanced interfaces. Training in the Basic interface was preceded by an introduction to climate change science workshop, attended by participants from a number of government sectors (including NMS), NGOs and regional organisations - this enhanced their understanding of climate variability and climate change, climate projections and other areas of interest such as extreme sea level and tropical cyclones. Over 95% of participants who attended this workshop found it to be useful for their work. Over 95% of participants who completed the Intermediate and Advanced Climate Futures training felt confident using the tool to provide projections to stakeholders.

"Knowing how to use Climate Futures is a big plus for us as advisors to government's key policymakers on planning, development, infrastructure, agriculture and zoning" – Federated States of Micronesia

"My project will benefit greatly as the information that will be provided will ensure better and informed project management giving a better direction on infrastructure resources to capitalize on" – Nauru

Pacific Climate Futures training in Nauru.

CliDE training in Vanuatu.

During the in-country visits to install CliDE and *Pacific Climate Futures* several other capacity building activities were conducted, including:

- Scientists from the PCCSP conducted seminars on topics of particular relevance to specific countries, such as: climate features; tropical cyclones; extreme sea level; the South Pacific Convergence Zone; climate change and oceans and climate data management, tools and trends;
- Liaison, relationship building and promotion of PCCSP: Consolidating and building stronger relationships with partners in government, regional organisations and other climate related projects in partner countries; and
- Many articles were published and interviews conducted as a result of media alerts written and disseminated to local media during the visits. This helped build the PCCSP and the Australian Government's profile, as well as promote the profile of the NMS and other local agencies.

2.2.4 Attachments

In 2011, three Pacific islanders were seconded to the PCCSP with the purpose of building the climate science research capacity. The Principal Scientific Officer of Climate and Ozone Services from the Samoa Meteorology Department and the Assistant Director of Climate and Special Services from the Papua New Guinea National Weather Service each spent six weeks working with their PCCSP colleagues at the Bureau of Meteorology. A Masters student from the University of the South Pacific in Fiji spent two weeks working with PCCSP colleagues at CSIRO Hobart.

The participant from Samoa focused on documenting the trends in observed and modelled air temperature over the South Pacific region, assigning statistical significance to this and determining the extent to which the pattern of observed trends resembles the pattern of modelled trends. The participant from Papua New Guinea focussed on relating the drivers of the climate of Papua New Guinea with observed station data and will present this research in an oral presentation at the 10th International Conference on Meteorology and Oceanography in Noumea in April 2012. The participant from Fiji worked on observations of the carbonate system and ocean acidification in the Western Pacific and will also present this work at the conference in Noumea in April 2012.

Each attachment included site-visits to CSIRO in Aspendale and Hobart to meet with PCCSP scientists working in other areas of the program. Participants were required to produce certain outputs, ranging from presentations to colleagues at the Bureau of Meteorology and CSIRO, to co-authored papers and oral presentations to be given at international conferences.

Participants were very positive about their attachments in the evaluations, highlighting the clear link between the work they were doing and the strengthening of their capacity to complete their duties in their home countries.

"The attachment has been extremely beneficial. It was provided the exposure to the experts, the tools and working conditions in which assists in the professional development of Samoa's representative. The experience gained from the attachment has allowed for reflection and to explore avenues through innovative thinking for which research development activities in Samoa Meteorology can be initiated" – Samoa Meteorology Department

"I can say with great confidence that the attachment has greatly enhanced my professional career development. Even though I enjoyed all the aspect of the attachment, the actual analysis of the data and conducting statistical analysis was the one that stood out for me personally. The benefit of working with respected Bureau scientist and creating that bond and understanding was a huge boost for my future work as far as networking is concerned" – Papua New Guinea National Weather Service

Pacific Climate Futures training in Palau.

2.3 Information dissemination

2.3.1 Preparation and publication of *Climate Change in the Pacific: Scientific Assessment and New Research*

Climate Change in the Pacific: Scientific Assessment and New Research was published at the end of 2011. This two-volume 530 page report provides the most extensive compilation of climate change science research ever undertaken for the Pacific.

The report development followed the IPCC model of a series of drafts starting with a Zero Order Draft (completed July 2010), a First Order Draft (completed February 2011) and a Second Order Draft (completed July 2011), with the final version completed in October 2011. The report was coordinated by a group of nine lead authors, three scientific editors and small coordination and communication team. The coordinating lead authors met monthly.

The report also had ten other lead authors, over 100 contributing authors from CSIRO, BoM, Pacific government agencies and regional organisations. The First Order Draft and Second Order Draft of the report were peer-reviewed by Dr Graeme Pearman (Graeme Pearman Consulting Pty Ltd) and Dr Anthony Chen (University of the West Indies). Partner countries and regional organisations, in addition to DCCEE and AusAID, also reviewed and provided feedback on the drafts. All reviews were documented in comments registers and authors were asked to address the comments via this system. The three scientific editors as well as peers within CSIRO and BoM also provided extensive internal peer review to ensure the scientific integrity and rigour of the report.

Volume 2 of the report contains individual country reports on the current and future climate of each of the 15 partner countries. These reports were developed from the country climate summaries that participants at the PCCSP Climate Data, Variability and Change Research and Training Workshop, Darwin, 31 May – 9 June 2010 wrote. These summaries formed the basis for these reports and partner countries provided significant contribution to Volume 2 as it developed. The Volume 2 report also formed the basis for the summary brochures which representatives from each partner country extensively reviewed.

The report was laid out and designed by CSIRO designers. Editing and proof reading was undertaken by a combination of internal and external contractors.

As of 31 December 2011, 26 peer reviewed papers and three book chapters had been published or were in press in academic journals, five papers had been submitted and 23 were in preparation. Many of these papers are cited in the report, further supporting the robust nature of the science contained in the report.

2.3.2 Launch and distribution of *Climate Change in the Pacific: Scientific Assessment and New Research*

The report was released in Australia on 25 November 2011 and two of the scientific editors, Scott Power (Bureau of Meteorology) and Kevin Hennessy (CSIRO) were delegated spokespeople. The launch involved a 45-minute online media briefing hosted by the Australian Science Media Centre. Scott Power and Kevin Hennessy presented for 10 minutes, highlighting key findings from *Climate Change in the Pacific*. A question and answer session followed. Twenty journalists attended along with ten other attendees. This included a number of Pacific journalists who were in Australia as part of an Asia Pacific Journalism Centre Program.

Immediately following this event, a media release was sent via the CSIRO media database reaching over 2800 contacts. This media release was also sent out to all PCCSP media and general contacts reaching more than 1000 other contacts. It was also sent to the UN Small Islands List Serve, the UN Climate List Serve and the Pacific Climate group email list.

This event and subsequent media release resulted in substantial media coverage across a range of outlets. Analysis indicated there were 141 pieces of coverage. This was made up of 95 stories by Australian media outlets and 46 from overseas including:

- Print in Australia – 4
- National Radio – 1
- Overseas Radio – 6
- Online Australian – 90
- Online overseas – 40

The release and findings of *Climate Change in the Pacific* (CCiP) were covered in several Australian daily newspapers including *The Age* (Page 5), The *Sydney Morning Herald*, *The Australian*, and *The Advertiser*. Scott Power was interviewed for segments on the ABC Radio's *The World Today* and *Pacific Beat*. Kevin Hennessy was also interviewed live on *Radio Australia*. There was also some international coverage ranging from the UK's *Telegraph*, *Scoop* in New Zealand, and Samoa's *Talamua*. A short story which focused on the ocean related findings of CCiP aired on the Australia Network's ABC news which broadcasts to over 40 countries across Asia and the Pacific. Subsequent news stories were also seen promoted on twitter.com. *Radio Australia, Pacific Beat, ABC Environment* and 14 other users 'tweeted' links to articles written about the *Climate Change in the Pacific* release. It should be noted that all Pacific coverage is likely to be an underestimate due to the difficulty in evaluating local media in the Pacific.

On 6 December 2011, the report was highlighted at a joint Australian Government / Secretariat of the Pacific Environment Programme Event held at the 17th Conference of the Parties (COP17) to the United Nations Framework Convention on Climate

Change (UNFCCC) in Durban. The event was opened by the Australian Minister for Climate Change, the Honourable Greg Combet, and also included opening remarks from the Honourable Ronald Aisiki, Papua New Guinea's Vice Minister for Climate Change and Forestry. The Master of Ceremonies was Netatua Pelesikoti, Director of the Climate Change Division in SPREP. Presentations included:

- Climate Change in the Pacific – Scientific Assessment and New Research: Scott Power
- Climate science needs in the Pacific: Ms Rossylynn Pulehetoa-Mitiepo, Coordinator Niue Climate Change Project, Department of Meteorology and Climate Change
- Pacific Climate Futures: Making climate projections accessible for adaptation planning, Mr Salesa Kaniaha, Vanuatu Meteorology and Geo-hazard Department, Ministry of Infrastructure and Public Utilities, Vanuatu
- The Secretariat of the Pacific Community's New Book on Climate Change, Brian Dawson, Senior Climate Change Advisor, SPC
- Pacific overview and vote of thanks, David Sheppard, Director General SPREP.

The event was very well attended by many Pacific Islanders including several UNFCCC National Focal points. The demand to attend the event outweighed the capacity of the venue. Although the venue only allowed for 50 seats, during Minister Combet's speech over 70 people were present. Other high-level attendees included:

- Ewen McDonald, AusAID Deputy Director General
- Dr Subho Banerjee, Deputy Secretary of the Adaptation, International & Regulatory Group
- Julia Feeney, Director in the UN Security Council Taskforce Department of Foreign Affairs and Trade
- Louise Hand, Australia's Climate Change Ambassador
- John Moffat Fugui, Minister for the Environment, Climate Change, Disaster Management, Solomon Islands.

The event was promoted via fliers distributed widely at the venue, an entry submitted to the COP17 daily program, UN email list serves, Pacific email list serve, distribution of fliers to media and personal invitations.

Minister Combet's office issued a media release which created additional media interest.

Channel 10's the *7pm Project* highlighted CCiP and some of its key findings as a lead-in to the program's story on COP17:

"New research today has spelled disaster for some of our Pacific neighbours. The CSIRO and Bureau of Meteorology has confirmed what Pacific nations have known for years, which is that their islands are being swallowed by the ocean. Fiji, Papua New Guinea, the Cook Islands, Samoa, Vanuatu and many more, are facing increased extreme rainfall, hotter days, warmer nights and rising sea levels. For countries like Tuvalu, gardens no longer grow and it may be the first country to be eradicated as a result of climate change..." – 7pm Project

This story was syndicated on 29 stations across Australia. This story represents a notable inclusion in Australian mainstream media.

Gillian Cambers did two interviews in relation to the PCCSP side event at COP17, including one live with ABC's the World Today and one with ABC Radio's Pacific Beat. Subsequent print stories were also produced across ABC's online platforms. One of the ABC stories was also syndicated in the Solomon Star newspaper.

A complete list of media coverage from the *Climate Change in Pacific* launch events is provided at Appendix 2.

A distribution and dissemination plan was developed for all publications. Implementation of this plan commenced in November/December 2011. As a show of recognition to the partner countries and as a way to facilitate the sharing of these publications with local audiences, in-country contacts were encouraged to hold national launches of the brochures and reports. This key component of the ongoing dissemination strategy commenced with a launch in Vanuatu held simultaneously with the Australian media launch. The in-country launches will continue during 2012. This involves working with the partner countries to not only facilitate and support a launch event, but also to actively support their plans to share the research with their stakeholders.

The reports have been well-received in-country and also amongst researchers in the Pacific:

"I am finding the report very very useful. Besides the work in Pacific Islands, I do a lot of work in the Coral Triangle region with climate adaptation and we are using and guiding people to the report constantly. Really nice work, we joke that we wish you guys would do the same thing for the US States, Territories and Freely Associated States in the Pacific" – Lead Coordinating Editor of the Pacific Islands, Regional Climate Assessment (PIRCA) effort for the Marine, Freshwater and Terrestrial Ecosystems on Pacific Islands in the Assessment, NOAA

2.3.3 Preparation of brochures in English and local languages

In response to the need to provide scientific information to different audiences, a series of brochure products were developed over the course of the PCCSP. This included two regional brochures and 15 individual brochures summarising the current and future climate of each partner country.

The two regional brochures were developed in response to requests for specific events. The first of these was a six-page brochure, which targets leaders or the PCCSP partner countries. This brochure outlined the purpose and objectives of the PCCSP and some background to climate change in the Pacific. This was distributed to Pacific Island country leaders at the Pacific Islands Forum held in Port Vila from 3-6 August 2010. The second regional product was an eight-page brochure about *Climate Variability and Change in the Pacific islands and East Timor*. This was distributed to participants at side events at the 16th Conference of the Parties (COP 16) in Cancun in December 2010. Both of these brochures were also used extensively on in-country visits as awareness raising resources.

The individual country brochures that summarise the climate of the 15 partner countries were developed with extensive input provided by representatives from each of the partner countries. These also underwent internal review and drafts were reviewed by the PCCSP Management Committee. The brochures summarise the findings for each country contained in Volume 2 of the report in a user-friendly format suitable for a wider audience.

The timing of these brochures was advanced in response to a request to have them ready in time to be launched at the 2011 Pacific Islands Forum. This proved challenging as the brochure summaries needed to be developed in parallel with the completion of the *Climate Change in the Pacific* report. Unfortunately the launch did not occur at the Pacific Islands Forum. The brochures were later released and highlighted in the Australian Foreign Minister Kevin Rudd's opening remarks to a meeting of Commonwealth and Developing Small States' Foreign Ministers held in Perth on 25 October 2011 in the lead up to the Commonwealth Heads of Government Meeting.

Following the release, electronic versions of the brochures were made available on the PCCSP website and an announcement was provided to partner countries, people on the PCCSP contacts database, the United Nations Small Islands States List Serve, the United Nations Climate List Serve, the Pacific Network email list and the Red Cross regional newsletter. In addition, brochures were distributed to all partner countries, regional organisations and internal stakeholders with a distribution survey for monitoring and evaluation purposes and to encourage the in-country launch process. The brochures were also widely distributed and highlighted at the side-event at COP17.

In-country launches of the brochures were held in Kiribati and Samoa and the brochures were launched alongside the report in Vanuatu in November 2011. The country brochures were very well-received. Some examples of feedback from the countries include:

"Thanks so much to the team for your assistance throughout the years in preparing this, it is a very excellent piece of work and good to use Nauru for awareness purposes" – Nauru

"There were some positive feedback from people from different sectors – they find the information very useful, ideal for sector planning. A Land Management Officer of MNRE thought it was an excellent publication. It was one of the most popular brochure on the day since we have about a few left at the end of the day from the 100 we received. So we might need some more in future. We like to thank you for the support extended to us thus far" – Samoa

In response to requests from partner countries, as well as part of a continued effort to share the comprehensive research and engage with regional audiences, each country brochure will be translated into a local language. As funding was not available through the PCCSP for this, additional funding to complete this activity was approved through the ICCAI Platform.

Each country brochure is being translated into one local language per country for release early next year. Translations are being managed by the University of the South Pacific's Language Centre, checked by national meteorological services and departments of language in partner countries, and sent to contacts at AusAID Posts before printing.

2.3.4 Launching PCCSP tools

Two web-based climate tools (the Pacific Tropical Cyclone data portal and the Pacific Climate Change Data Portal) and the climate database management system (CliDE) were launched at the Regional Meteorological Services Directors Meeting in Majuro, Republic of the Marshall Islands on 10 August 2011.

A media release was distributed to the PCCSP media contacts database on the morning of the launch. This included over 100 contacts from local media organisations from partner countries, Pacific-wide media as well as Australian and New Zealand Pacific-focused media. Nanette Woonton (SPREP) distributed our media release to SPREP's contact database. On 11 August, an updated media release and an accompanying photo from the launch was sent to meteorological departments of all partner countries. This included a vote of thanks for support as well as a suggestion to pass the release on to local media contacts. The media release was published in the 12 August issue of the *Marshall Islands Journal* as was a follow up article on the launch in the 19 August issue. An announcement was also sent to the PCCSP database of over 800 Pacific contacts.

The *Pacific Climate Futures* tool was officially launched and highlighted at the joint Australian Government-SPREP side-event at COP17 in December 2011. Salesa Kaniaha from the Vanuatu Meteorology and Geo-hazard Department presented an overview presentation of the tool

and demonstrated how it could be used to inform adaptation planning and risk management. There was an overwhelmingly positive response to the tool with a member of the audience from the Caribbean requesting the tool be developed for other regions of the world.

2.3.5 Media coverage and capacity building

The PCCSP media strategy focused particularly on the release of the new research towards the end of 2011. However, opportunistic activities were also pursued with a particular emphasis on media in partner countries. At least 219 media items were published or broadcast as a result of the PCCSP activities. The focus of these falls into three broad categories: media as a result of the two launches of *Climate Change in the Pacific* (154), the Greenhouse 2011 conference (24) and in-country visits (at least 41).

Visits to PCCSP partner countries have been highlighted by local media on many occasions. PCCSP teams were briefed on the local media and techniques for engaging with the media before departing and were provided with a media alert and local media contacts. Media alerts were typically bolstered with quotes from PCCSP partner country representatives, e.g.

"PCCSP Climate Futures will help us to access and provide better scientific information need for Palau to plan for future climate change." – Palau

"The PCCSP tool will enhance our ability to include climate change considerations in national development plans and strategies" – Papua New Guinea

"I think Climate Futures is one of the highlights of the Pacific Climate Change Science Program… Basically, information on the future climate or future climate scenarios is something which was lacking in the past… Now with the availability of these tools and information, we can now improve on our climate services, not only providing information on the current climate but also what is the likely future climate scenario" – Solomon Islands

Local media were very responsive to media alerts issued jointly with the local contact agency in each country. Almost all visits have seen coverage in local media, usually print media. Media monitoring in the Pacific is extremely challenging so exact numbers are hard to ascertain; a minimum estimate would be 41 items of coverage. However, many local radio stations for example would air the story five to ten times in a day increasing the audience reached.

During the Greenhouse 2011 conference, the PCCSP team sought the opportunity to raise the profile of the PCCSP in the lead up to the release of research results later in the year. As a result of PCCSP efforts, 24 media stories were published or broadcast during the conference (Appendix 3). Many of these were produced by the two Pacific journalists who were sponsored to attend the conference as part of a PCCSP capacity building program conducted in partnership with SPREP. The sponsored journalists were Pita Liguala, a Fijian print journalist from the regional service PACNEWS and Rozalee Nongebatu from Solomon Islands Broadcasting Corporation (SIBC). Twelve stories were written by Pita Liguala and published by PACNEWS. Rozalee Nongebatu broadcast seven stories on SIBC radio during the conference and two follow-up stories after the conference.

A report by Rozalee about how she benefited from the experience at Greenhouse 2011 and her recommendations for future similar activities indicated that she found it a great opportunity that broadened her knowledge base and developed her networks with Pacific scientists. She recommended further training was needed for journalists from the 15 PCCSP partner countries. Following her attendance at Greenhouse 2011, Rozalee was awarded the Solomon Islands RAMSI Special Coordinators Media Encouragement Award, particularly for her reporting on environmental issues such as climate change.

Five other programs broadcast or published stories on climate change in the Pacific or the Pacific Climate Change Science Program during the conference, including the lead story on AM-ABC Radio National on 4 April 2011, the first day of the conference. Four of these were radio and one was print and one was a New Zealand radio program. Several participants from PCCSP partner countries attending the conference were interviewed for stories. Four of these stories were the result of a PCCSP media alert or proactive contact by the PCCSP.

Due to the difficulty in monitoring media in the Pacific countries, it is hard to establish if they were published more widely. However, some of the stories were picked up by at least six other Pacific news/websites.

The PCCSP-sponsored partner country participants at Greenhouse 2011 were also offered the opportunity to undertake an interview to camera during the conference. Many of the participants found this an excellent learning opportunity in building their communication skills. Some of these interviews were used to produce a short video that was played during the COP17 side-event. This video has been extremely useful at a range of outreach events.

Over the course of the PCCSP, a media contacts database was established and relationships developed with media across the Pacific. The PCCSP media database contains 112 Pacific-focused and based journalists.

In November 2011 PCCSP scientists did a one day climate change science workshop for 14 Asia Pacific editors and senior journalists. The journalists were in Australia as part of an AusAID supported a five-week Asia Pacific Journalism Centre program on reporting climate change and the environment. The journalists were very receptive and particularly interested in the new information available about their countries in the country-specific brochures.

In addition to the media database, emphasis was also placed on establishing a contact database in order to continue to effectively communicate with stakeholders. The country engagement activities and workshops which helped communicate the basics of climate change science and the tools also provided an opportunity to build this extensive contacts database. This database of 877 contacts was used to communicate all major announcements and used to track our engagement with stakeholders.

An extensive photo database was also established under the PCCSP to consolidate and manage images and facilitate use of images for publications. This database contains nearly 4000 images from the Pacific.

2.3.6 Website and e-newsletter

The PCCSP website www.pacificclimatechangescience.org was written and designed in the second half of 2010 and went live in December 2010. Visitor tracking did not commence until August 2011.

Media releases, launch events and subsequent media coverage generated significant activity on the PCCSP website. During the seven-week period encompassing the three launches (27 October – 15 December 2011), the PCCSP website had a total of 4751 visits. This was a 550% increase in visits when compared to the seven-week period immediately preceding (7 September – 26 October). During the launch period, visitors from 109 different countries accessed the website. The majority of visitors accessed the site from Australia (46%), the USA (12%) and Fiji (9%).

During the period Nov 25 – Dec 9 2011, the PCCSP website received 6141 page views. Sixty percent of all page views were to the publications page, which contains the CCiP report and the Country Brochures

An e-newsletter was designed with the same look and feel of the website and two editions were sent during the course of the PCCSP. Unfortunately resourcing did not allow for this to continue, but positive feedback was received on editions sent.

3. The way forward

During 2010, a gaps and needs analysis of climate change science in the region was conducted. This was based on feedback from partner countries and regional organisations during three regional workshops and several in-country visits. The analysis highlighted areas that need to be addressed after the PCCSP has been completed, namely:

- Broader communication of climate change science to partner country stakeholders;
- Further capacity building and education;
- Reducing uncertainty in atmospheric and oceanic projections;
- Robust attribution of climate change to natural and/or anthropogenic factors;
- Updated regional and country specific atmospheric and ocean projections for 2020 to 2100 and beyond for new Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment emission scenarios and climate simulations;
- More detailed projections for extreme events including co-incident extreme events; and
- Detailed atmospheric and oceanic projections for selected economic sectors and regions.

This analysis formed the basis for the follow-up climate change science, communication and capacity-building included in the Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) program, which runs until June 2013.

Appendix 1:

List of PCCSP Publications

Published

Brown, J. R., Power, S. B., Delage, F. P., Colman, R. A., Moise A. F. and Murphy B. F. 2011. Evaluation of the South Pacific Convergence Zone in IPCC AR4 climate model simulations of the 20th century, *Journal of Climate*, Volume 24 (6), 1565-1582 doi:10.1007/s00382-011-1192-0.

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Kuleshov, Y., De Wit, R., Phan, J., Schweitzer, M., Dowdy, A. and Jones, D. 2011. Pacific Climate Change Science Program: Improving the understanding of tropical cyclone climatology. *Bulletin of PORSEC*, Vol. 5.2, 2-5.

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Submitted

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Brown, J.N., Brown, J.R., Muir, L., Murphy, B., Risbey, J., Sen Gupta, A., Wijffels S.E. and Zhang X. Implications of CMIP3 model biases and uncertainties for climate projections in the western Pacific. To be submitted to *Journal of Climate*.

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Tory, K.J., Chand, S.S., Dare, R.A. and McBride J.L. The development and assessment of a model-, grid- and basin-independent tropical cyclone detection scheme.

Tory, K.J., Chand, S.S., Dare, R.A. and McBride J.L. Assessment of a model-, grid- and basin-independent tropical cyclone detection scheme in selected CMIP3 models.

Wijffels, S. and Muir, L.. The anatomy of ocean warming 1950-2000.

Zhang, X., Church, J., Platten S. and Monselesan, D. Projection of subtropical gyre circulation change and associated sea-level change in the Pacific Ocean based on CMIP3 climate models. Under preparation, to be submitted to *Geophys. Res. Lett.*

Appendix 2:

Media Coverage Summary – Launch of Climate Change in the Pacific

Print: (4)
Weekend Australian
Sydney Morning Herald
The Age
Herald Sun

Wires: (1)
PACNEWS

Overseas Radio: (6)
Radio NZ Wellington (2 articles)
Radio NZ Auckland (2 articles)
Radio NZ Christchurch (2 articles)

National Radio: (2)
ABC World Today (2 Stories)

Television: (2)
The Australia Channel
Channel Ten- The Project

Australia Online: (89)
ABC (2 articles)
ABC [World Today] (2 articles)
ABC Asia Pacific (2 articles)
ABC Radio Australia News
Ararat Advertiser
Armidale Express
Augusta Margaret River Mail
Australian Network News
Avon Valley Advocate
Baird Maritime
Banyule and Nillumbik Weekly
Bay Post
Bendigo Advertiser
Blayney Chronicle
Blogs Courier Mail
Boorowa News
Braidwood Times
Brisbane Times
Bunbury Mail
Camden Haven Courier
Casey Weekly Berwick
Central Midland & Coastal Advocate
Coastal Times
Cowra Community News
Daily Liberal
Eastern Riverina Chronicle
Eco Voice
Eco News
Get Sustainable
Gippsland Times
Goondiwindi Argus
Goulburn Post
Herald Sun
Hills News
Hume Weekly
Inverell Times
The Lowyinterpreter
Latrobe Valley Express
Mandurah Mail
Mudgee Guardian
Muswellbrook Chronicle
Naracoorte Herald
Narooma News
Narromine News
News.com.au
Northern Argus
Nyngan Observer
Pacific Beat
Parkes Champion-Post
Parramatta Sun
Peninsula Weekly
Port Lincoln Times
Port Macquarie News
Queensland Country Life
Rousehill-Stanhope Gardens News
Science in Public
Southern Highland News
Southern Weekly
St Marys-Mt Druitt Star
Stock and Land
Stock Journal
Sunraysia Daily
Tenterfield Star
The Advertiser
The Age
The Armidale Express
The Avon Valley Advocate
The Border Mail
The Canberra Times
The Courier
The Islander
The Macleay Argus
The Medical News
The Newcastle Herald (2 articles)
The Rural
The Sydney Morning Herald (2 articles)
The Times
The Wimmera Mail-Times
WA Today
Warrnambool Standard
Western Advocate
Whyalla News
Wollondilly Advertiser
Overseas Online: (50)

AllVoices
Agrometerology.org
AndhraNews.net
Asian News International
Bright Surf
Climatepasifika.blog
Climate Desk
Conserve online
China National News
Daily Telegraph
Democratic Underground
Environment Business Week
Environmental Research Web
Eurekalert
Global Maritime Social Network
Pacific Islands Forum Sec
Hamara Photos
Honolulu Star-Advertiser
Independent Media Center
IndyBay
Japan Herald
MedIndia
Mena Fn
Middle East North Africa Financial Network
Net India123
New Zealand Energy &
NewKerala.com
News Track India
North Korea Times
Philippine Times
PhysOrg.com
Proplanta.de
GRAND TOTAL: 154

Radio NZ
RxPG News
San Francisco Bay Area
Relief Web
Science Codex
Science Daily
Science newsline
Scoop NZ
Scottrade
Solomons Star (2 articles)
Solomons Times
Talamua- Samoa
Telegraph.co.uk
Terra Daily
Webindia123.com
Yahoo! India

Appendix 3:

Pacific Climate Change Science Program media coverage during Greenhouse 2011

Table 1: Coverage by Pacific island journalists

PACNEW – Pita Liguala 12 stories	1. Pacific Climate Change Science Program explains role 2. Australian government committed in tackling climate change: Combet 3. Scientific evidence proves that impacts of climate change is real: Dr Garnaut 4. Latest climate change information captured in new CSIRO book 5. Tuvalu not comfortable with environmental refugees status 6. Sea level rise in the Pacific will contribute to environmental refugees 7. Scientist warn of social unrest in Pacific river deltas in future 8. Adaptation in many river deltas in Pacific islands is short term 9. Dredging only a short term solution for flooding in Fiji 10. Rainfall patterns changing in the Pacific 11. Ocean depth and ice no longer a barrier to Climate change 12. Humidity increases will make more places inhabitable in the future
Rozalee Nongebatu from Solomon Islands Broadcasting Corporation 7 stories and 2 follow-up stories	1. 03/04/2011 Hiriasia Solomon poster presentation 2011 2. 04-04-2011 Australian Minister For Climate Change And Energy Efficiency 3. 04/04/2011 Dr Roemich – Scripps Institution of Oceanography 4. 04/04/2011 Environmental Refugees 5. 05/04/2011 PCCSP Head On Climate Change In The Pacific 6. 07/04/2011 River Deltas and Relocation 7. 08/04/2011 Advantages and risks in advancing climate change science in small tropical islands – by Dr Gillian Cambers **Post conference follow-up stories** 8. CliDE Software For Met Service 9. Hirisia on PCCSP Honiara Workshop

Table 2: Coverage by Australian and New Zealand media

ABC Radio Nation-AM Program	**08:00 04/04/2011 Pacific scientists say sea levels affect farming** Researchers from 14 Pacific countries as well as East Timor share their latest research into the impact of climate change at a week-long conference in Cairns. Some are reporting that sea level rises are causing erosion and affecting fishing and farming. Included interviews with Netatua Pelesikoti, Climate Change focal point, SPREP, Gillian Cambers, PCCSP Program Manager, Kevin Hennessy, Principal Scientist, 'Ofa Fa'anunu, Director of Meteorology, Tonga Meteorology Service.
Radio Australia – Pacific Beat	**No solid scientific data on Pacific climate change** No solid scientific data on Pacific climate change. … Reporter: Joanna McCarthy. Speakers: Gillian Cambers, program manager, Pacific Climate Change Science, CSIRO; David Hiriasia, director, Solomon Islands Meteorological Service.
Radio Australia – Clement Paligaru	Interviews with Gillian Cambers, Program Manager about the PCCSP and Patrick Nunn, School of Behavioural, Cognitive and Social Sciences, The University of New England, Armidale. http://blogs.radioaustralia.net.au/english/2011/pacific/the-pacifics-forgotten-climate-refugees
Cairns Post	Story about Climate Change refugees and Tuvalu- interview with Hilia Vavae, Chief Meteorological Officer, Tuvalu Meteorology Services –full article at **Appendix 3**
Pacific Radio News – New Zealand	Ruci Jean Farrell News producer interviewed Gillian Cambers, PCCSP Program Manager, and Hilia Vavae, Chief Meteorological Officer, Tuvalu Meteorology Services

Table 3: Links to re-publication of stories by other Pacific news agencies/website

Samoa Observer	ABC AM story: http://samoaobserver.ws/index.php?option=com_content&view=article&id=32387:pacific-scientists-&catid=55:pacific-region&Itemid=65 Ran PACNEWS story –Rainfall patterns changing in the Pacific http://www.samoaobserver.ws/index.php?option=com_content&view=article&id=32525:rainfall-patterns-&catid=64:sunday-reading&Itemid=82
Samoa.news.com	Ran PACNEWS story –Rainfall patterns changing in the Pacific http://www.samoanews.com/viewstory.php?storyid=25355&edition=1302170400&newssection=RegionalNews
Islands Business	Ran PACNEWS story on the PCCSP: http://www.islandsbusiness.com/news/index_dynamic/containerNameToReplace=MiddleMiddle/focusModuleID=130/focusContentID=23402/tableName=mediaRelease/overideSkinName=newsArticle-full.tpl Ran PACNEWS story on river deltas http://www.islandsbusiness.com/news/index_dynamic/containerNameToReplace=MiddleMiddle/focusModuleID=130/focusContentID=23418/tableName=mediaRelease/overideSkinName=newsArticle-full.tpl
Assist America website	Ran PACNEWS story about PCCSP: http://assistamerica.countrywatch.com/rcountry.aspx?vcountry=172&topic=CBWIR&uid=5083849
Pacific Immigration directors website	Ran PACNEWS story on Tuvalu not comfortable with environmental change refugees status http://www.pidcsec.org/news.asp?pageID=2145885662&RefID=2141740514

Appendix 4:
Project Reports

1.1 Rehabilitation of meteorological data

Program
Pacific Climate Change Science Program

Component
Component 1: Current and recent climate

Project Title
1.1 Rehabilitation of meteorological data

Project Leader
David Jones

Researchers
Simon McGree, Dean Collins (deceased), David Jones, numerous participants from Partner Countries (see authors of papers).

Methodology

- Extraction of historical data from Partner Country meteorological archives and international archives. Complete data for 68 rainfall, 37 temperature and 3 pressure stations across the study region.
- Temporal aggregation (monthly, seasonal and annual averages) and quality control for outliers and errors. Comparison with independent data sources, including NOAA, NIWA and Australian data archives.
- Aggregation of station metadata (station histories etc) for stations to support homogeneity assessments and subsequent adjustments.
- Homogeneity testing using F (difference of slopes) and T (difference of means) statistics drawing heavily on the RHtest methodology.
- Adjustment of time series for detected and corroborated inhomogeneities ("step changes") in time series.
- Calculation of trends (point and gridded data) and spatial averages from point and gridded data.
- Statistical significant testing of trends and variations. Comparison with independent variables such as measures of the South Pacific Convergence Zone.
- Development of online data store including data upload, interactive analysis and graphing tools.

Main Research Findings

- The following summarises the key results for temperature.
- There has been a widespread warming.
- The updated homogeneous records indicate that mean temperatures have increased at all available Pacific island stations over 1960-2010, with rates ranging from +0.08 to +0.20ºC/decade. The strongest warming trends are found in Papua New Guinea and French Polynesia. None of the updated homogeneous records show cooling over the past 70, 50 or 30 years.
- Trends in maximum and minimum temperatures are very similar to those of mean temperature at most stations, apart from in Fiji, Tonga and Niue where there is a tendency for greater warming in the daytime. The amount of warming in the wet and dry seasons is also similar at most stations, although stations in Fiji, Tonga and Niue display a bias toward greater warming during the wet. A simple regional mean of Pacific island series shows a sustained trend of +0.16°C/decade over 1960-2010 and indicates that 2010 was the warmest year on record averaged across the stations. This regional mean station series compares favourably with a regional mean series extracted from a global gridded dataset. Overall, the background warming in Pacific Island temperature records over the past half-century is consistent with that expected from human-induced global warming.
- The following summarises the key results for rainfall.
- The study of rainfall has confirmed the homogeneity of most rainfall series as supported by statistical analyses of time series and careful analysis of metadata from sites.
- The updated rainfall series clearly show the large interannual variability experienced in the tropical Pacific which is linked to such factors as the El Nino-Southern Oscillation, changes in the South Pacific Convergence Zone and the Interdecadal Pacific Oscillation.
- This variability is large compared with the magnitude of long-term rainfall trends, making them less spatially coherent than those for temperature. Trends in total annual rainfall for the longest available rainfall records, indicate a general increase in rainfall totals north-east of the South Pacific Convergence Zone over the past 50 years, with mainly declines to the south-west of the South Pacific Convergence Zone, and north of the Inter Tropical Convergence Zone just west of the International Date Line. This pattern of change is generally reflected in both wet and dry seasons.
- Analysis of the last two decades reveals a marked reversal of earlier trends, consistent with a shift of the South Pacific Convergence Zone back to its climatological position since 1990 with increase in the south-west Pacific and decreases to the north-east of the South Pacific Convergence Zone. Unlike changes in temperature, which are dominated by background global warming, the lack of a sustained trend in rainfall suggests that Pacific rainfall patterns continue to be strongly influenced by natural climate variability.

Papers: Published and in press

Substantial contributions to "Climate Change in the Pacific: Scientific Assessment and New Research. Volume 1: Regional Overview. 2011" and "Climate Change in the Pacific: Scientific Assessment and New Research. Volume 2: Country Reports. 2011"

Papers: Under preparation and submitted

D. Collins, S. McGree, D.A. Jones, E. Skilling, H. Diamond, Ofa Fa'anunu, D. Hiriasia, S. Hugony, R. Hutchinson, K. Inape, L. Jacklick, T. Moniz, M. Ngemaes, A. Porteous, P. Samson, S. Seuseu, L. Tahani, F. Talagi, F. Teimitsi, U. Toorua, M. Vaiimene, V. Vuniyayawa and H. Vavae. 2012. An updated analysis of homogeneous temperature trends at Pacific Island stations. Likely to submit to Climatic Change.

S. McGree, D. Collins, D. Jones, B. Campbell, A. Akapo, H. Diamond, O. Fa'Anunu, D. Hiriasia, S. Hugony, K. Inape, L. Jacklick, T. Moniz, M. Ngemases, A. Peltier, A. Porteois, P. Samson, S. Seuseu, E. Skilling, L. Tahani, F. Talagi, F. Teimitsi, U. Toorua, M. Vaiimene, V. Vuniyayawa and H. Vavae. 2012. An updated analysis of homogeneous rainfall trends at Pacific Island stations and East Timor. Likely to submit to Climatic Change.

1.2. Data rescue and data management including CliDE

Program
Pacific Climate Change Science Program

Component
Component 1: Current and recent climate

Project Title
1.2 Data rescue and data management including CliDE

Project Leader
David Jones

Researchers
Rod Hutchinson, Andrew Howard, Simon McGree, Matthew Bastin, David John Martin, D. Collins, numerous participants from Partner Countries: E. Skilling, H. Diamond, Ofa Fa'anunu, D. Hiriasia, K. Inape, L. Jacklick, T. Moniz, M. Ngemaes, A. Porteous, P. Samson, S. Seuseu, L. Tahani, F. Talagi, F. Teimitsi, U. Toorua, M. Vaiimene, V. Vuniyayawa and H. Vavae. 2012.

Methodology

- Examination of existing Climate Data Management applications lead to a decision towards Open Source software in lieu of proprietary software and solutions.
- Hardware was selected on the basis that the provider would guarantee the technical capability to withstand fluctuations in temperature, humidity, and electricity, and to reduce the probability of the system being subject to viruses, software changes and accidental deletion.
- Development of database was modelled on the Australian Data Archive of Meteorology (ADAM) databases with modifications to fit the local conditions.
- The database was provided to each recipient in an operating condition which included a station catalogue and a basic climate data set where available.
- The database design included provision to fulfill the requirements of the World Meteorological Organisation's 'Global Framework for Climate Services', thereby providing the basis for future climate services and science for Partner Countries.
- Database is designed to be highly scalable and expandable into the future by not being tied to particular operating systems.
- The system is intended to assist with data management, help maximise the quality of the observation data and the value that can be obtained from the observations and station metadata..
- The database is a web browser based application and does not require any special software apart from a modern operating system and browser.
- Analysis has been undertaken of current data available in Partner Countries, in international databases including NIWA (New Zealand), NOAA (U.S.A) and Bureau of Meteorology.
- International data has been collated and provided to Partner Countries for those situation where international holding go beyond local digital data holdings.

Main Research Findings

- Most small National Meteorological Services (NMS) use spreadsheets to manage their climatological observations and produce reports.
- In nearly all countries spreadsheets are duplicated and changes, corrections and updates are not audited or recorded in any way. They are not managed at a corporate level but are dependent on individuals for successful operation, introducing substantial key person risk.
- This project has greatly improved the usability and accessibility of NMS data archives, allows them to improve their services and undertake more climate research in future years through significant capacity building in data management including reducing risk in loss/destruction of paper records.
- Most of NMS electronic records are available in three data sets. The National Institute of Water and Atmospheric research (NIWA) in New Zealand, and from NOAA. However, while some of these datasets the fine level quality control normally associated with indigenous data management is uncertain and there appears to be extensive periods of missing and/or erroneous data and disagreement between datasets. However, many datasets do not cover the full range of stations available or the complete record length.
- In addition there is anecdotal evidence to suggest that miss-keying may have taken place, and thus quality control processes should be introduced using statistical techniques to find the most likely errant data and cross checking those with the original record.
- Papua New Guinea and Solomon Islands data up to independence is retained the Australian Bureau of Meteorology's "ADAM" dataset. Most of it is key-entered from observation booklets and rainfall registers which are retained in the National Archives of Australia at Burwood. ADAM probably contains the most reliable pre-independence electronic holdings. Post independence electronic data have been lost in PNG but extensive paper record remains.
- The project has identified substantial outstanding data holdings on paper which could be digitised to advance climate knowledge in the region. Activities in this area have commenced; for example in Vanuatu a project has commenced which will digitise the remaining 40% of undigitised climate data, thereby providing a complete climate record for this nation.

Papers: Published and in press

Major contributions to "Climate Change in the Pacific: Scientific Assessment and New Research. Volume 1: Regional Overview. 2011" and "Climate Change in the Pacific: Scientific Assessment and New Research. Volume 2: Country Reports. 2011".

Papers: Under preparation and submitted

A number of technical documents have been prepared on CliDE.

1.3 Improving the understanding of tropical cyclone climatology

Program
Pacific Climate Change Science Program

Component
Component 1: Current and recent climate

Project Title
1.3 Improving the understanding of tropical cyclone climatology

Project Leader
Yuriy Kuleshov

Researchers
Andrew Dowdy, Roald de Wit

Methodology

The statistical significance of the linear trends in the various tropical cyclone (TC) time series was assessed in two ways.

- We have calculated the statistical significances by Monte Carlo simulation (10,000 iterations) involving re-sampling the time series with and without replacement and forming a sampling distribution of the linear trend from which we determine the significance level.
- We have also subjected the TC time series to a single breakpoint testing procedure. This is a nonparametric procedure on the basis of the Mann-Whitney statistic.

Main Research Findings

- A TC archive for the Southern Hemisphere (SH) has been revised and it now consists of TC best track data for the "satellite era" i.e. the TC seasons from 1969/70 to 2009/10. Based on SH TC archive data, analyses have been undertaken to understand the variability and change in TC occurrences across the SH (area south of the equator, 30°E to 120°W). Much of the variability of TCs can be understood (and even predicted in advance) using broad-scale indices which describe the El Niño-Southern Oscillation (ENSO) phenomenon.
- TC trends in the SH have been examined. For the 1981/82 to 2006/07 TC seasons, there are no apparent trends in the total numbers of TCs, nor in numbers of 970 hPa TCs (such TCs being called severe in the SH). In the Pacific region, no significant trends in the total numbers of TCs, or in the proportion of the most intense TCs, have been found. Quality of best track TC data in the SH was examined in detail and it was concluded that issues with the data homogeneity limit our ability at the present time to answer the important question of how TC activity in the SH is changing and its possible relationship to global climate change more generally.
- To provide means for accessing detailed information and data on historical TCs for the SH, a specialized website for disseminating results and data was developed using OpenLayers platform, allowing dynamic map navigation of detailed information for user-selected regions.

Papers: Published and in press

Kuleshov, Y., 2011: Tropical cyclone climatology, in book "Climatology", Intech, ISBN 979-953-307-337-7 (in press).

Kuleshov, Y., R. de Wit, M. Schweitzer, J. Phan, A. Dowdy, D. Jones, 2011: Pacific Climate Change Science Program: Improving the understanding of tropical cyclone climatology, Bulletin of PORSEC, Vol. 5.2, 2-5.

Dowdy, A., and Y. Kuleshov, 2011: An analysis of tropical cyclone occurrence in the Southern Hemisphere derived from a new satellite-era dataset, International Journal of Remote Sensing (accepted).

Kuleshov, Y. L. Qi, D. Jones, R. Fawcett, F. Chane-Ming, J. McBride and H. Ramsay, 2010: On developing a tropical cyclone archive and climatology for the South Indian and South Pacific Oceans, in book *Indian Ocean Tropical Cyclones and Climate Change*, Ed. Y. Charabi, Springer, 189-197, doi: 10.1007/978-90-481-3109-9_23.

Kuleshov, Y., R. Fawcett, L. Qi, B. Trewin, D. Jones, J. McBride and H. Ramsay, 2010: Trends in tropical cyclones in the South Indian Ocean and the South Pacific Ocean, *J. Geophys. Res*. 115, D01101, doi:10.1029/2009JD012372.

Papers: Under preparation and submitted

Dowdy, A., L. Qi, D. Jones, H. Ramsay, R. Fawcett and Y. Kuleshov. Tropical cyclone climatology of the South Pacific Ocean and its relationship to the El Niño-Southern Oscillation, submitted to *Journal of Climate*.

2.1 El Niño-Southern Oscillation (ENSO)

Program
Pacific Climate Change Science Program

Component
2. Understanding large scale climate features

Project Title
2.1 El Niño-Southern Oscillation (ENSO)

Project Leader
Scott Power

Researchers
Brad Murphy, Scott Power, François Delage

Methodology

- Documented impact of ENSO on climate in the partner countries and both its seasonal and interannual variability.
- Explained inter-annual climate variations in partner countries due to ENSO with respect to changes in large-scale climate features (e.g. SPCZ, West Pacific Monsoon).
- Examined variations in ENSO impacts on partner country between different types of El Niño events (classical and Modoki).
- Evaluated ENSO in Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) climate model simulations of the 21st Century.
- Examined changes in ENSO under global warming through investigation of IPCC AR4 climate model projections for the 21st century

Main Research Findings

- ENSO is associated with large rainfall variations in many Partner Countries. Countries east of 160ºE and close to the equator experience above-average rainfall during an El Niño, while other countries experience drier than normal conditions. The average response in wet season rainfall is generally in the same direction for both canonical and El Niño Modoki events, but weaker for El Niño Modoki, except Nauru and Tarawa (Kiribati) where the Modoki response is greater.
- CMIP3 models show varying degrees of skill in reproducing the strength and frequency of ENSO events, from very weak to overly strong canonical and Modoki events. In general, models with excessively strong canonical ENSO variability also have excessively strong Modoki variability, or too weak for both. Most of the CMIP3 models reproduce the canonical ENSO pattern is reasonably well, but most don't reproduce the Modoki pattern well.
- Many models may not simulate the correct changes in rainfall during El Niño and La Niña events for some Partner Countries due to errors in how they simulate ENSO. As the line between regions of warmer and cooler water during ENSO events is shifted too far west in many models, countries may have the wrong temperature anomaly during El Niño and La Niña events. The pattern of rainfall response to ENSO events is also shifted too far west in many models, and is too strong or too weak in some models.
- 21st century interannual variability in the region will continue to be largely driven by ENSO. Unfortunately, climate models do not provide consistent projections of changes in the frequency, intensity and patterns of future El Niño and La Niña events. As the climate changes, however, some aspects of the climate experienced in some regions during El Niño and La Niña events may change (e.g. future El Niño events will tend to be warmer than El Niño events experienced in the past).

Papers: Published and in press

Irving, D.B., Perkins, S.E., Brown, J.R., Sen Gupta, A., Moise, A.F., Murphy, B.F., Muir, L., Coleman, R.A., Power, S.B., Wijffels, S.E., Delage, F.P. 2011. Selecting Global Climate Models for regional climate change projections: a case study for the Pacific island region. *Climate Research* in press.

Perkins, S.E., D.B. Irving, J.R. Brown, S.B. Power, A.F. Moise, R.A. Colman, and I. Smith, 2011: CMIP3 ensemble climate projections over the western tropical Pacific based on model skill. *Climate Research*, (in press).

Power, S.B., F. Delage, R. Colman, and A. Moise, 2011: Consensus on 21st century rainfall projections in climate models more widespread than previously thought. *J. Climate*, (accepted).

2.2 South Pacific Convergence Zone

Program
Pacific Climate Change Science Program

Component
2. Understanding large scale climate features

Project Title
2.2 South Pacific Convergence Zone (SPCZ)

Project Leader
Scott Power

Researchers
Jo Brown, Scott Power, Francois Delage, Brad Murphy, Aurel Moise, Rob Colman, Christine Chung

Methodology

- Initiated, organised and ran first ever international conference dedicated to examination of the SPCZ in observations and in climate model simulations of the 20th and 21st centuries.
- Documented main features of the SPCZ and both its seasonal and interannual variability.
- Developed method to characterise major features of SPCZ (e.g. latitude and spatial orientation).
- Examine changes in the SPCZ under global warming. Evaluation of the South Pacific Convergence Zone in Intergovernmental Panel on Climate Change IPCC Fourth Assessment Report AR4 Climate Model Simulations of the Twentieth Century
- Understanding how the SPCZ may change in the future requires the use of global coupled atmosphere–ocean models. It is therefore important to evaluate the ability of such models to realistically simulate the SPCZ. We examined changes in the SPCZ in IPCC AR4 climate model projections for the 21st century

Main Research Findings

- The simulation of the SPCZ in 24 coupled model simulations of the twentieth century was examined. The models and simulations are those used for the (AR4) of the IPCC. The seasonal climatology and interannual variability of the SPCZ is evaluated using observed and model precipitation. Twenty models simulate a distinct SPCZ, while four models merge intertropical convergence zone and SPCZ precipitation. The majority of models simulate an SPCZ with an overly zonal orientation, rather than extending in a diagonal band into the southeast Pacific as observed. Two-thirds of models capture the observed meridional (north-south) displacement of the SPCZ during El Niño and La Niña events. The four models that use ocean heat flux adjustments simulate a better tropical SPCZ pattern because of a better representation of the Pacific sea surface temperature pattern and absence of cold sea surface temperature biases on the equator. However, the flux-adjusted models do not show greater skill in simulating the interannual variability of the SPCZ. While a small subset of models does not adequately reproduce the climatology or variability of the SPCZ, the majority of models are able to capture the main features of SPCZ climatology and variability, and they can therefore be used with some confidence for future climate projections.
- The response of the SPCZ to climate change is examined using simulations from 16 coupled climate models under the A2 emission scenario carried out for the Intergovernmental Panel on Climate Change Fourth Assessment Report. Characteristics of the austral summer SPCZ in the late twenty-first century are compared with the late twentieth century: the orientation and latitude of the SPCZ precipitation band; the area and intensity of precipitation within the SPCZ; and the eastern extent of the SPCZ. Changes in the SPCZ position are examined using a simple linear fit to the band of maximum precipitation and using a "pattern matching" technique. Both techniques find no consistent shift in the slope or mean latitude of the austral summer SPCZ. However, many models simulate a westward shift in the eastern edge of the SPCZ in austral summer, with reduced precipitation to the east of around 150ºW. The westward contraction of the SPCZ is associated with a strengthening of the trade winds in the southeast Pacific and an increased zonal sea surface temperature gradient across the South Pacific. The majority of models simulate an increase in the area of the SPCZ and in mean and maximum precipitation within the SPCZ, defined by a 6 mm/day precipitation threshold, consistent with increased moisture convergence in a warmer climate. Changes in the SPCZ response to ENSO are examined using ENSO precipitation composites. The SPCZ has a reduced slope and is shifted towards the equator in the A2 multi-model mean El Niño composite.

Papers: Published and in press

Brown, J. R., Scott B. Power, Francois P. Delage, Robert A. Colman, Aurel F. Moise, Bradley F. Murphy, 2011: Evaluation of the South Pacific Convergence Zone in IPCC AR4 Climate Model Simulations of the Twentieth Century. J. Climate, 24, 1565–1582. doi: http://dx.doi.org/10.1175/2010JCLI3942.1

Brown, J.R., A.F. Moise, and F.P. Delage, 2011: Changes in the SPCZ in IPCC AR4 future climate projections. *Climate Dynamics*, (in press).

Irving D, Perkins S, Brown JR, Sen Gupta A, Moise A, Murphy B, Muir L, Colman R, Power S, Delage F, & Brown JN, 2011: Evaluating global climate models for the Pacific Island region. *Climate Research*, 49, 169-187. doi:10.3354/cr01 http://www.int-res.com/articles/cr_oa/c049p169.pdf.

Moise, A.F., and F.P. Delage, 2011: New climate model metrics based on object-orientated pattern matching of rainfall. *J. Geophys. Res*., 116, D12108, doi: 10.1029/2010JD015318.

Perkins, S.E., D.B. Irving, J.R. Brown, S.B. Power, A.F. Moise, R.A. Colman, and I. Smith, 2011: CMIP3 ensemble climate projections over the western tropical Pacific based on model skill. Climate Research, (in press).

Power, S., 2011, Understanding the South Pacific Convergence Zone and its impacts, *Eos Trans*. AGU, 92(7), 55, doi:10.1029/2011EO070006.

Power, S.B., F. Delage, R. Colman, and A. Moise, 2011: Consensus on 21st century rainfall projections in climate models more widespread than previously thought. *J. Climate*, (accepted).

2.3 Western Pacific Monsoon (WPM) and the Intertropical Convergence Zone (ITCZ)

Program
Pacific Climate Change Science Program

Component
2. Understanding large scale climate features

Project Title
2.3 Western Pacific Monsoon (WPM) and the Intertropical Convergence Zone (ITCZ)

Project Leader
Rob Colman

Researchers
Rob Colman, Aurel Moise, Francois Delage

Methodology

- Documented impact of the ITCZ and the WPM on climate in the partner countries and both its seasonal and interannual variability.
- Evaluation of the WPM and the ITCZ in Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) Climate Model Simulations of the Twentieth Century
- Understanding how the ITCZ and the WPM may change in the future requires the use of global coupled atmosphere–ocean models. It is therefore important to evaluate the ability of such models to realistically simulate the ITCZ and the WPM. We examined changes in the ITCZ and the WPM in IPCC AR4 climate model projections for the 21st century.

Main Research Findings

The Western Pacific Monsoon

- The Western Pacific Monsoon is associated with a seasonal reversal of winds that brings heavy rainfall to the region north of Australia. Variations in the timing, position, intensity, longevity and extent of the monsoon account for much of the rainfall variability in this region. East Timor, Papua New Guinea and the Solomon Islands are within the monsoon region for all or most years. Vanuatu, Tuvalu and parts of Kiribati lie outside the average monsoon domain but nonetheless are affected by the monsoon during some years. In the Northern Hemisphere, Palau lies within the westerly domain during most years, while parts of the Federated States of Micronesia and Marshall Islands are only affected by the monsoon in some years.
- Year-to-year variability in the extent of the monsoon-affected region is significant, especially on the eastern edge, where it varies by more than 5000 km between maximum and minimum extent. The two most extreme maximum eastern extents of the monsoon domain occurred during the strong El Niño years of 1983/84 and 1997/98. The north-south variability of the westerly wind domain is much less pronounced.
- Overall, with only a few exceptions, the CMIP3 climate models capture the major climatic features of the monsoon, including the seasonal reversal of the surface winds and the dominance of summer rainfall over winter rainfall.
- 21st century projections: There is a general tendency for an amplification of the seasonal cycle of rainfall in the West Pacific Monsoon region. Westerly winds over the region show a relatively weak enhancement in December-February, while in June-August there are enhanced westerlies in the Northern Hemisphere contrasting with weaker westerlies in the Southern Hemisphere.

Intertropical Convergence Zone

- Seasonal and year-to-year variability in the position and intensity of the ITCZ can have significant impacts on low latitude Pacific nations due to its meridional (north-south) narrowness and large rainfall gradients. As the mean seasonal shift of the ITCZ is only 2° of latitude in the central Pacific, even small shifts in overall location can result in large impacts. The PCCSP Partner Countries affected by the ITCZ are Palau, the Marshall Islands and the Federated States of Micronesia.
- The latitude of the ITCZ varies from year-to-year. For example, during 1979-1999 the ITCZ tended to be approximately 3° closer to the equator during El Niño conditions than during La Niña conditions. Rainfall amounts in the ITCZ are also strongly influenced by ENSO.
- A small downward trend in total rainfall is apparent over the 1979–1999 period for this region, and the trend is stronger in December-February than June-August.
- Climate models on average reproduce the seasonal cycle of ITCZ rainfall amounts reasonably well, although uncertainties in the observations are large in this region, precluding stronger conclusions. On interannual time scales, most models are able to reproduce the equatorward shift under El Niño conditions and the poleward shift under La Niña conditions found in the observations, except for those models not showing significant ENSO variability.
- 21st century changes in rainfall averaged over the ITCZ show a general increase in June-August, with little change in December-February, thereby amplifying the current seasonal cycle. There is an increase in the area of the ITCZ in all models in June-August, and nearly all models in December-February. Models suggest the ITCZ may shift equatorward in March-May and June-August by a small amount.
- The ramification of these and related projected changes are discussed in Volumes 1 and 2 (BoM-CSIRO 2011) and in the country reports of the affected partner countries.

Papers: Published and in press

Irving D, Perkins S, Brown J.R, Sen Gupta A, Moise A, Murphy B, Muir L, Colman R, Power S, Delage F, & Brown JN, 2011: Evaluating global climate models for the Pacific Island region. *Climate Research*, 49, 169-187. doi:10.3354/cr01 http://www.int-res.com/articles/cr_oa/c049p169.pdf.

Moise, A.F., and F.P. Delage, 2011: New climate model metrics based on object-orientated pattern matching of rainfall. *J. Geophys. Res*., 116, D12108, doi: 10.1029/2010JD015318.

Perkins, S.E., D.B. Irving, J.R. Brown, S.B. Power, A.F. Moise, R.A. Colman, and I. Smith, 2011: CMIP3 ensemble climate projections over the western tropical Pacific based on model skill. *Climate Research*, (in press).

Power, S.B., F. Delage, R. Colman, and A. Moise, 2011: Consensus on 21st century rainfall projections in climate models more widespread than previously thought. *J. Climate*, (accepted).

Papers: Under preparation and submitted

Smith, I.N., A.F. Moise, and R.A. Colman, 2011: Large scale features in the western Pacific and their representation in climate models. *J. Geophys. Research*, (submitted).

3.1 Global Climate Model Projections

Program
Pacific Climate Change Science Program

Component
3. Climate Projections

Project Title
3.1 GCM projections

Project Leader
Kevin Hennessy

Researchers
Damien Irving, Sarah Perkins, Penny Whetton

Methodology

- In consultation with Components 2 and 4, evaluate the reliability of 24 global climate models and identify models suitable for use in climate projections
- Calculate projected changes in temperature, rainfall, wind, humidity, solar radiation, evaporation and drought
- Describe projections in a technical report "Climate Change in the Pacific: Scientific Assessment and New Research", respond to comments from peer-review, use results in brochures, presentations and media interviews
- Contribute to assessment of downscaled projections

Main Research Findings

After assessing the performance of 24 global climate models, 18 were considered suitable for projections. Projections were developed for three 20-year periods (centred on 2030, 2055 and 2090) and three emissions scenarios (low-B1, medium-A1B and high-A2).

Temperature

- 2030: 0.5 to 1.0ºC warmer, regardless of the emissions scenario
- 2055: 1.0 to 1.5oC warmer with regional differences depending on the emissions scenario
- 2090: 1.5 to 2.0oC for B1 (low emissions), 2.0 to 2.5oC for A1B (medium emissions) and 2.5 to 3.0oC for A2 (high emissions)
- More extremely hot days and warm nights

Rainfall

- Annual mean rainfall generally increases
- 2030: increases 0–0.3 mm per day throughout most of the region, rising to 0.3–0.6 mm per day between latitudes 5°N and 10°S, for all emissions scenarios
- 2055: the increases are generally similar to 2030, but reach 0.9–1.2 mm per day between latitudes 5°N and 10°S, with decreases of 0–0.3 mm per day between Vanuatu and Tonga in the B1 (low) and A1B (medium) emissions scenarios.
- 2090: the increases are generally similar to 2055, but reach 1.2–1.5 mm per day for B1 (low) emissions and 1.5–1.8 mm per day for A1B (medium) and A2 (high) emissions between latitudes 5°N and 10°S
- An increase in the number of heavy rain days (20-50 mm) and the intensity of extreme rainfall events (occurring once in 20 years)

Wind

- Wind speed decreases slightly in the equatorial and northern parts of the region, with small increases in the south

Humidity and solar radiation

- Relatively small changes, generally with increasing humidity and decreasing solar radiation

Potential evapotranspiration

- Increases except along the equator and over Papua New Guinea

Droughts

- Decrease in frequency

Papers: Published and in press

Perkins, S. 2011. Biases and model agreement in projections of climate extremes over the tropical Pacific, *Earth Interactions*, 15, 1–36. doi: http://dx.doi.org/10.1175/2011EI395.1

Irving, D.B., Perkins, S.E., Brown, J.R., Sen Gupta, A., Moise, A.F., Murphy, B.F., Muir, L., Coleman, R.A., Power, S.B., Wijffels, S.E., Delage, F.P. 2011. Selecting Global Climate Models for regional climate change projections: a case study for the Pacific island region, *Climate Research*, 49, 169-187. doi: 10.3354/cr01028.

Perkins, P., Irving, D.B., Brown, J.R., Power, S.B., Murphy, B.F., Moise, A.F., Colman, R.A., Delage, F.P. 2012. CMIP3 ensemble climate projections over the western tropical Pacific based on model skill. *Climate Research*, doi: 10.3354/cr01046.

3.2 Tropical cyclones

Program
Pacific Climate Change Science Program

Component
3. Climate projections

Project Title
Project 3.2 Tropical cyclones

Project Leader
Debbie Abbs

Researchers
Debbie Abbs, Craig Arthur, Mohar Chattopadhyay, Savin Chand, John McBride, Tony Rafter, Nick Summons, Kevin Tory

Methodology

- Application of the Genesis Potential Index (GPI) to CMIP3 outputs over the South Pacific to infer changes in the formation frequency and the Maximum Potential Intensity of tropical cyclones and to infer the changes in the large-scale environment underlying these changes.
- Development of a new tropical cyclone detection scheme (the curvature vorticity parameter – CVP) and the application of that scheme to a subset of CMIP3 models to provide projected changes in the formation frequency of tropical cyclones.
- Application of the CSIRO Direct Detection Scheme (CDD) to CMIP3 outputs and 60-km CCAM simulations to provide projected changes in formation frequency and tracks of TCs in the South Pacific. The CCAM tracks were further analysed to provide guidance on likely changes in the intensity of tropical cyclones affecting the South Pacific.
- TC tracks from the CCAM outputs were further scaled for use in the Tropical Cyclone Risk Model to provide information on current and future climate TC-related wind hazard for the region.

Main Research Findings

- The analysis of the global models using the CVP and CDD techniques shows that they are able to reproduce the climatology of tropical cyclones for the current climate.
- Application of these 2 techniques and the GPI method to the outputs from CMIP3 models shows considerable variability in the projected changes between both the global models and the three techniques.
- When the CDD technique is applied to CCAM outputs the projected changes show little variability between the 6 simulations considered and may be due to the use of a single modelling system for the downscaled runs analysed. Importantly, the CCAM simulations under-estimate the occurrence of tropical cyclones occurring east of 180°E
- Projections based upon these different modelling systems and analysis techniques show that tropical cyclone frequency in the PCCSP region is likely to decrease by the late 21st century. There is a moderate level of confidence in this projection, with little consistency found in the magnitude of the projected changes between either the models or the analysis methods.
- Most CCAM simulations project an increase in the proportion of the most severe storms in the Southwest Pacific and a southward movement in the latitude at which maximum intensity occurs. This coincides with a reduction in cyclonic wind hazard north of 20°S and regions of increased wind hazard south of 20°S.
- In the Northern basin (0N-15N), most simulations project an increase in the proportion of storms occurring in the weaker categories. For the North Pacific region, there is a general reduction in cyclonic wind hazard between the current and future climate simulations as a result of a decrease in storm frequency close to the equator.

Papers: Published and in press

Knutson, T.R., McBride, J.L., Chan, J., Emanuel, K., Holland, G., Landsea, C., Held, I., Kossin, J.P., Srivastava, A.K., and Sugi, M., (2010), Tropical cyclones and climate change: *Nature Geoscience*, v. 3, p. 157-163.

Papers: Under preparation and submitted

Chattopadhyay, M. and Abbs, D., (2012), On the Variability of Projected Tropical Cyclone Genesis in GCM Ensembles. *Tellus A* (submitted)

Chattopadhyay, M. and Abbs, D., (2012), Influence of large scale circulation on TC variability in GCM and RCM simulation. (in preparation)

Summons, N., Arthur, C., and Abbs, D., (2012), Tropical Cyclone Wind Hazard in the West Pacific. (in preparation)

Tory, K. J., R. A. Dare, N. E. Davidson, J. L. McBride and S. S. Chand (2012). The importance of low-deformation vorticity in tropical cyclone formation. (in preparation)

Tory, K. J., S. S. Chand, R. A. Dare, and J. L. McBride (2012). The development and assessment of a model-, grid- and basin-independent tropical cyclone detection scheme. (in preparation)

Tory, K. J., S. S. Chand, R. A. Dare, and J. L. McBride (2012). Assessment of a model-, grid- and basin-independent tropical cyclone detection scheme in selected CMIP3 models. (in preparation)

Chand, S. S, J. L. McBride, K. J. Tory and K. J. E. Walsh (2012). Contrasting austral summer ENSO regimes and their impacts on tropical cyclones over the central southwest Pacific. (in preparation)

3.3 Dynamical downscaling

Program
Pacific Climate Change Science Program

Component
3. Climate projections

Project Title
3.3.Dynamical downscaling

Project Leader
Jack Katzfey

Researchers
Jack Katzfey, John McGregor, Kim Nguyen, Marcus Thatcher, Mohar Chattopadyhay

Methodology

- Select six GCMs to downscale, only A2 emissions scenario used.
- CCAM run on global even grid of approximately 60 km, using only bias-corrected sea surface temperatures from the GCMs and sea ice concentrations.
- Simulations were from 1961-2100.
- Seven countries were chosen to downscale to 8 km resolution
  - East Timor, Papua New Guinea, Solomon Islands, Vanuatu, Fiji, Samoa, Federated States of Micronesia
  - Only three of the CCAM 60 km simulations were downscaled (UKHadCM3, GFDLCcm21 and ECHAM5)
  - Only three time slices were completed: 1980-2000, 2045-2065, 2080-2099
- A second set of 60 km and 8 km simulations were completed using a mixed-layer ocean spectrally nudged to the host SSTs

Main Research Findings

The CCAM 60 km simulations reproduce the current climate generally better than the host GCMs, more for temperatures, but also to some extent for rainfall. The CCAM 8 km simulations captured the effects of the local topography on the climate and its change.

Papers: Published and in press

Nguyen, K. C., Katzfey, J., and McGregor, J. L., 2011: Global 60 km simulations with CCAM: evaluation over the tropics. Climate Dynamics, Doi: 10.1007/s00382-011-1197-8

Papers: Under preparation and submitted

Nguyen, K.C., Katzfey, J. J., and McGregor, J. L. Ensemble prediction of future circulation and rainfall changes over the tropics. To be submitted to Climate Dynamics.

3.4 Additional Downscaling

Program
Pacific Climate Change Science Program

Component
3. Climate projections

Project Title
3.4 Additional downscaling

Project Leader
Jack Katzfey

Researchers
Jack Katzfey, Kim Nguyen, Jason Evans (UNSW), Kevin Walsh (UMelb), Jim Renwick (NIWA), Ray Arritt (IOWA State)

Methodology

- Use additional regional climate models to downscale over the Pacific
- Used WRF (UNSW), RegCM and MM5 (IOWA), PRECIS (NIWA) and Zetac (UMelb)
- Used the GFDLCM21 60 km CCAM simulation for the A2 scenario
- Time periods simulated: 1980-2000, 2045-2065
- Also each group ran a simulation nested within NCEP2 reanalyses

Main Research Findings

The main research finding was that although the various models used different dynamics, physics and model set-ups, the climate change signal was broadly similar. Only slight degradation of the current climate results was noted when models were nested within CCAM versus NCEP2.

Papers: Published and in press

None as yet

3.5 Statistical downscaling

Program
Pacific Climate Change Science Program

Component
3. Climate projections

Project Title
3.5 Statistical downscaling

Project Leader
Philip Kokic

Researchers
Steven Crimp, Warren Jin

Methodology

- Developed effective climate data editing tools.
- Developed methodology for statistical downscaling that improves on standard existing approaches in terms of forecast accuracy (Kokic, Crimp & Howden, 2011 & Kokic, Jin and Crimp). Method accounts for seasonality, cross-variables and temporal dependencies in the data and utilizes predictors from GCMs
- Undertook out-of-sample validation of the downscaling methodology (Kokic, Jin and Crimp). Assessment was made in terms of out-of-sample predictive accuracy accounting for forecast error, and testing of spatial, temporal and cross-station consistency of the forecasts
- Developed an effective estimation method in the present of partially missing data using the Estimate-Maximise (EM) algorithm (Kokic & Jin). This was important for the project as most climate station data has partially missing data
- Developed software systems to automate the statistical downscaling methodology

Main Research Findings

- We applied the statistical downscaling method to 17 climate stations in the Pacific. Produced projected daily climate data for 2021-2040 for all 17 locations as well as the corresponding base-period simulations (1981-2000). Also generated projected climate data for 2046-2065 for 12 locations.
- The countries for which downscaling was performed were Cook, Islands, Micronesia, Fiji, Marshall Islands, Samoa, Solomon Islands and Vanuatu. Climate data from other islands was judged to be of insufficient quality to produce reliable statistical downscaled projections.
- Downscaling was performed using predictors derived from 3 global climate models: UK HadCM3, ECHAM 5 and GFDLCM 2.1 all using the A2 midrange emission scenario
- The results of statistical downscaling show a projected increase in average daily rainfall in most locations for most host models, except for the Marshall Islands, where average daily rainfall is projected to decline in two out of the three cases. In some locations, the range of rainfall projections is quite wide, e.g., in Micronesia and the Marshall Islands, which indicates that rainfall is projected with less certainty in these locations. Average maximum and minimum temperature are consistently projected to increase in all locations regardless of which GCM predictors are used to drive the statistical downscaling.

Papers: Published and in press

Kokic, P, Crimp, S., & Howden, M. 2011. Forecasting climate variables using a mixed-effect state-space model. *Environmetrics*, 22, 409-419

Papers: Under preparation and submitted

Kokic, P. Jin, H. & Crimp S. Bootstrap simulation of climate variables using quantile matching methods. Likely to submit to *Environmetrics*.

Kokic, P. & Jin, H. Parameter estimation in a mixed-effect state-space model with missing data. Likely to submit to *Statistics & Probability* Letters

3.6 Tailored Projections

Program
Pacific Climate Change Science Program

Component
3. Climate projections

Project Title
3.6 Tailored Projections

Project Leader
John Clarke

Researchers
Tim Erwin and Kevin Hennessy

Methodology

- Identify tailored products needs through in-country meetings and workshops
- Development of prototype climate futures tool
- Staged process of cyclical road testing and further development (road-testing was conducted on three separate occasions)
- In-country testing of connectivity and identification of countries that required local installation (all other countries to access the tool via the internet)
- Define appropriate country regions and sub-regions based on EEZs and major climate driver locations in consultation with researchers from Components 2 and 3.
- Establish CSIRO server and migrate software
- Develop final version of the web-tool
- Develop training materials and evaluations
- Install in country where required
- Assist Component 5 with planning for in-country training
- Conduct in-country training in each of the 15 partner countries
- Evaluate the training through user surveys while in country.
- Plan for follow-up visits

Main Research Findings

- The web-tool, called *Pacific Climate Futures* has been very well received by the partner countries as well as at the UNFCCC 17th Conference of the Parties in Durban, South Africa.
- Based on the training evaluation results, all participants attained new skills as a direct result of the in-country training. Almost half of those trained to Advanced level indicated they are now confident in their ability to produce tailored projections for impact assessments in their country. This is a very significant outcome as, for many participants this was their first exposure to climate projections work. Further, in several countries there is at least one participant who has indicated they are confident they can train others.
- We have succeeded in developing a tool that simplifies the communication of climate projections and provides the functionality needed by the impacts and adaptation communities in the PCCSP partner countries.

Papers: Published and in press

The Pacific Climate Futures web-tool is referred to in:

Clarke JM, Whetton PH, Hennessy KJ (2011) 'Providing Application-specific Climate Projections Datasets: CSIRO's Climate Futures Framework.' In F Chan, D Marinova and RS Anderssen (eds) MODSIM2011, 19th International Congress on Modelling and Simulation. Perth, Western Australia. December 2011 pp. 2683-2690. (Modelling and Simulation Society of Australia and New Zealand). www.mssanz.org.au/modsim2011/D10/wongsosaputro.pdf. (Note that this is a peer-reviewed publication).

Papers: Under preparation and submitted

We are in the early stages of planning two papers:

1. On the capacity building aspects of delivering the web-tool and associated training. We intend to invite Gillian Cook, Lily Frencham and Kevin Hennessy to be co-authors.
2. On the technical aspects of the web-tool itself. We intend to invite Penny Whetton and Kevin Hennessy to be co-authors.

4.1 ENSO variability and climate change

Program
Pacific Climate Change Science Program

Component
4. Oceans and sea level rise

Project Title
4.1 ENSO variability and climate change

Project Leader
Jaclyn Brown / Susan Wijffels

Researchers
Jaclyn Brown, Les Muir, Alex Sen Gupta, Susan Wijffels, Paul Durack

Methodology

- Use latest available salinity observations and statistical techniques to develop trend data of salinity changes in PCCSP region. Write journal paper.
- Use an array of available observations to determine ocean climate trends over last 50 years where possible.
- Explore the ability to use a multi-parametric analysis method to reconstruct climate trends in observations compared to models. Write Journal paper.
- Analyse control runs of CMIP3 output to determine if and where model drift becomes significant.
- Design a method to quantify model drift. Write journal paper on drift.
- Adjust model output for drift.
- Compare observed trends with detrended model output over same period for model evaluation.
- Analyse performance of models for model evaluation paper
- Determine confidence levels for regional climate projections in country reports in collaboration with other components.
- Create projection information from CMIP3 model output for ocean climate out to 2100.
- Assess models for model biases in the PCCSP region and write journal paper.
- Write contribution to PCCSP report Vol 1 & 2.

Main Research Findings

- Climate trends in PCCSP region – PCCSP report Vol 1. Contributed to report showing observed climate change, likely changes to climate in the PCCSP region (such as SST warming) and communicating uncertainty where relevant.
- Climate projections at island scale – PCCSP report Vol 2. Provided country specific climate projections with a discussion of uncertainty for each.
- Model drift. – Journal paper (Sen Gupta et al.). Dedrifted the ocean components of the CMIP3 models. Found regions and variables where drift became important in the long term trend and adjusted projections accordingly.
- Observed salinity data set. – Journal paper. (Wijffels and Durack). Observational data sets of salinity was compiled and analysed for trends over the last 50 years. Found a freshening trend in the western Pacific.
- Trend analysis in ocean warming data. – Journal paper (Wijffels and Muir).
- Multi-parametric analysis was adopted to identify warming trends in the ocean and how these compare to model simulations.
- Model biases – Journal paper (Brown J.N. et al). Comprehensive review and discussion of model biases in CMIP3 relevant to making climate projections in the PCCSP region.
- Model selection – Journal paper (Irving et al). Contribution of ocean model analysis for model selection in PCCSP report and subsequent journal paper.

Papers: Published and in press

Irving, D.B., Perkins, S.E., Brown, J.R., Sen Gupta, A., Moise, A.F., Murphy, B.F., Muir, L., Coleman, R.A., Power, S.B., Wijffels, S.E., Delage, F.P. 2011. Selecting Global Climate Models for regional climate change projections: a case study for the Pacific island region, *Climate Research*, doi: 10.3354/cr01028

Durack, P.J., Wijffels, S. 2010. Fifty-year trends in global ocean salinities and their relationship to broad-scale warming, *Journal of Climate*, doi: 10.1175/2010JCLI3377.1

Papers: Under preparation and submitted

Sen Gupta, A. et al. Climate drift in the CMIP 3 coupled climate models. *Journal of Climate or Climate Dynamics*, early 2011. (under review).

Wijffels, S. and L. Muir. The Anatomy of ocean warming 1950-2000. In prep.

Brown J.N.et al. Implications of CMIP3 model biases and uncertainties for climate projections in the western Tropical Pacific. To be submitted to special issue of Climatic Change in December.

4.2 Sea level projections for the Pacific Islands' region

Program
Pacific Climate Change Science Program

Component
4. Oceans and sea level rise

Project Title
4.2 Sea-level projections for the Pacific Islands' region

Project Leader
John Church

Researchers
Xuebin Zhang, Skye Platten, Neil White; Katja Dommenget

Methodology

- Analysis of sea level projections and associated processes, primarily of the AR4 simulations.
- Comparison of model projections with observational estimates where available.
- Model calculations to determine how long it takes for a melting ice sheet signal to be experienced in the Pacific.

Main Research Findings

- The observed sea level rise since 1972 can be well explained by ocean warming and glacier melt with additional contributions from the ice sheets and changes in terrestrial storage.
- Sea level in the region has risen by 2 to 10 mm/year from 1993-2009, which is up to three times the global average of 3.2 mm/year.
- Regional sea level change can be significantly affected by low-frequency (interannual to interdecadal) modes of climate variability. Ice sheet contributions to the ocean are felt rapidly in the PCCSP region.
- Regional projections of sea level rise in the PCCSP region are close to the global averaged rise.

Papers: Published and in press

Church, J.A., Woodworth, P.L., Aarup, T and Wilson, Editors, W.S. 2010. Understanding Sea-level Rise and Variability, Wiley-Blackwell Publishing, Chichester, UK. (427 pp; ISBN: 978-1-4443-3452-4 (paperback); 978-1-4443-3451-7 (hardback).

Woodworth, P.L., Church, J.A., Aarup, T. and Wilson, W.S. 2010. Chapter 1: Introduction. In: Understanding Sea-level Rise and Variability, Eds. John A. Church, Philip L. Woodworth, Thorkild Aarup and W. Stanley Wilson. Wiley-Blackwell Publishing, Chichester, UK. (427 pp; ISBN: 978-1-4443-3452-4 (paperback); 978-1-4443-3451-7 (hardback).

Church, J.A., Roemmich, D., Domingues, C.M., Willis, J.K., White, N.J. Gilson, J.E., Stammer, D., Köhl, A., Chambers, D.P., Landerer, F.W., Marotzke, J., Gregory, J., Suzuki, T., Cazenave, A. and Le Traon, P.-Y. 2010. Chapter 6. Ocean temperature and salinity contributions to global and regional sea-level change. In: Understanding Sea-level Rise and Variability, Eds. John A. Church, Philip L. Woodworth, Thorkild Aarup and W. Stanley Wilson. Wiley-Blackwell Publishing, Chichester, UK. (427 pp; ISBN: 978-1-4443-3452-4 (paperback); 978-1-4443-3451-7 (hardback).

Church, J.A., Aarup, T., Woodworth, P.L., Wilson, W.S., Nicholls, R.J., Rayner, R., Lambeck, K., Mitchum, G.T., Steffen, K., Cazenave, A., Blewitt, G., Mitrovica, J.X. and Lowe, J.A. 2010. Chapter 13: Sea-level Rise and Variability – Synthesis and Outlook for the Future. In: Understanding Sea-level Rise and Variability, Eds. John A. Church, Philip L. Woodworth, Thorkild Aarup and W. Stanley Wilson. Wiley-Blackwell Publishing, Chichester, UK. (427 pp; ISBN: 978-1-4443-3452-4 (paperback); 978-1-4443-3451-7 (hardback).

Church, J.A. and White, N.J. 2011. Sea-level rise from the late 19th to the early 21st Century. *Surveys in Geophysics* 32, 585-602, DOI:10.1007/s10712-011-9119-1. http://www.springerlink.com/openurl.asp?genre=article&id=doi:10.1007/s10712-011-9119-1

Church, J.A., Gregory, J.M., White, N.J., Platten, S.M., and Mitrovica, J.X. 2011. Understanding and projecting sea level change. *Oceanography* 24(2):130–143, doi:10.5670/oceanog.2011.33.

Church, J.A. White, N.J., Konikow, L.F., Domingues, C.M., Cogley, J.G., Rignot E. and Gregory, J.M. 2011. Revisiting the Earth's sea-level and energy budgets for 1961 to 2008. *Geophys. Res. Lett.*, 38, L18601, doi:10.1029/2011GL048794. http://www.agu.org/journals/gl/gl1118/2011GL048794/

Papers: Under preparation and submitted

Lorbacher, K., Marsland, S.J., Church, J.A. and Griffies, S.M. In revision. Rapid barotropic sea-level rise from simulated ice-sheet melting scenarios. *Journal of Geophysical Research*.

Zhang, X., and Church, J., Linear trend of regional sea-level change in the Pacific Ocean ad its relationship with background decadal oscillation. Earlier manuscript was rejected by Journal of Climate, and it's now under revision to be resubmitted.

Zhang, X., Church, J., Platten, S. and Monselesan, D., Projection of subtropical gyre circulation change and associated sea-level change in the Pacific Ocean based on CMIP3 climate models. Under preparation, to be submitted to *Geophys. Res. Lett*.

4.3 Ocean acidification

Program
Pacific Climate Change Science Program

Component
4. Oceans and sea level rise

Project Title
4.3 Ocean Acidification

Project Leader
Bronte Tilbrook

Researchers
Mareva Kuchinke, Andrew Lenton

Methodology

- Historical data for total alkalinity (TA) and dissolved inorganic carbon (TCO_2) were compiled for the Pacific Island region (120°E -140°W and 38°S-30°N).
- The historical data were used to derive a TA-salinity relationship. This relationship was used to calculate monthly TA values from surface salinity.
- The calculated monthly TA values, and pCO_2 data from the Takahashi climatology, were then used to calculate the aragonite saturation state (Ω) of the seawater. Aragonite is the major mineral form of carbonate precipitated by corals and other important reef species. The saturation state of aragonite in seawater is related to coral calcification rates.
- An offline carbonate chemistry model coupled to IPCC AR4 model projections was used to project changes in aragonite saturation state for the period 2010-2090. An ensemble of six models under high, medium and low emission scenarios was used.
- The model outputs were assessed against the observations described above and a multi-model mean and statistics for seawater carbonate chemistry were calculated from the model projections.
- Worked with Sri Nandini, a Master's Student from the University of the South Pacific, on projected changes in ocean acidification.

Main Research Findings

- Aragonite saturation state (Ω) is a proxy for estimating calcification rates in corals. Values above 4 are considered optimal for supporting healthy reef ecosystems with values below 3.5 considered marginal. Coral reefs are usually not found where surrounding waters have Ω values below about 3, although local short-term variability can occur within lagoons, and other environmental variables like temperature can also influence the distributions of reefs.
- The mean value of Ω in surface waters of the study region has declined from about 4.6 in pre-industrial times to present day values of about 3.7.
- Surface seawater Ω varies spatially and temporally. Some countries are surrounded by waters with Ω fluctuating seasonally between 3.5 and 3.9.
- The Western Pacific will continue to see significant increases in the rate of ocean acidification, with decreases in pH and aragonite saturation state occurring under all emission scenarios.
- Ocean acidification in the future will be driven primarily by the increase in atmospheric CO_2, while ocean temperature and salinity changes play only a minor role in modulating the change.
- As atmospheric CO_2 levels are driving acidification change, the rate of change is linked to the emission scenario.
- The rate of ocean acidification is similar for the low, mid and high emission scenarios until about 2050 and diverges for the different scenarios in the second half of the 21st century due to differences in rates of increase of atmospheric CO_2 concentrations.
- Regionally, conditions that are considered marginal for supporting healthy reefs ($\Omega < 3.5$) will occur in the Central Equatorial Pacific in the next few decades. The reef ecosystems in the region of the South Equatorial Current will be the last to experience these conditions.
- All reefs in the Pacific Island region are predicted to be exposed marginal growing conditions ($\Omega < 3.5$) by about 2050, with the lowest values of Ω expected for the highest emission scenario.

Papers: Published and in press

Lenton A, N. Metzl, T. Takahashi, M. Kuchinke, R. J. Matear, T. Roy, S.C. Sutherland, C. Sweeney, and B. Tilbrook, in press. The observed evolution of oceanic pCO_2 and its drivers over the last two decades, Global Biogeochemical Cycles

Papers: Under preparation and submitted

Kuchinke, M., B. Tilbrook, and A. Lenton 2011 Ocean Acidification and the Aragonite Saturation State in the Pacific Island Region, in preparation for *Marine Chemistry*

Lenton A. (2011) Projected changes in pH and aragonite saturation state in the Western Pacific, in preparation for *Geophysical Research Letters*

4.4. Effects of climate variability and climate change on extreme sea level events

Program
Pacific Climate Change Science Program

Component
4. Oceans and sea level rise

Project Title
4.1 Effects of climate variability and climate change on extreme sea level events

Project Leader
Kathleen McInnes

Researchers
Kathleen McInnes, Ron Hoeke, Julian O'Grady, Kevin Walsh, Frank Colberg

Methodology

- A review of literature relevant for sea level extremes was carried out and published.
- An analysis of tide gauge data was undertaken to develop the extreme sea level annual climatologies. The hourly total water levels were deconstructed into their component parts comprising astronomical tides, non-tidal low frequency fluctuations in the sea surface (e.g. seasonal and ENSO variations) and the short term fluctuations due to local winds, waves and barometric pressure.
- To investigate storm surges along the entire Fiji coastline, a synthetic tropical cyclone and storm surge modelling study was undertaken. Tropical cyclones that have affected Fiji were characterised in terms of intensity, track and frequency for all years and La Niña and El Niño years. A population of 1000 plausible cyclones for that region were sampled. Temporally and spatially varying wind and pressure fields arising from each synthetic cyclone were modelled using an analytical cyclone model and a hydrodynamic model simulated the sea level response over Fiji. The modelled surge heights were then analysed statistically to evaluate storm surge return periods.

Main Research Findings

- To communicate the specific issues relating to extreme sea levels in the Pacific, a review paper was prepared at the outset of the PCCSP project (Walsh et al., 2011) which explained the role of ENSO, tropical cyclones, waves, surges and their interaction with island geometry in contributing to extreme sea levels.
- From the recommendations in the review article, extreme water climatologies were prepared for each tide gauge location showing the average variation throughout the year of the 95th percentile tide height, the seasonal and short term contributions, how they vary between La Niña and El Niño phases of the ENSO cycle and their contribution to total water levels. These were evaluated for each of the PCCSP countries tide gauges for the Volume 2 country summaries. They showed that tidal extremes clustered around either the solstices (June and December) for countries such as Papua New Guinea and eastern Federated States of Micronesia, the equinoxes (March and October) for the Marshall Islands, Kiribati, Tuvalu, Palau and southern Cook Islands and showed fairly uniform annual variation in countries such as Nauru, Vanuatu, Fiji, Tonga, northern Cook Islands. These differences were due to the differences in the dominant tidal characteristics at each location. The summaries also showed that higher than normal sea levels occurred in La Niña years in Palau, Papua New Guinea, Federated States of Micronesia, Tuvalu, Samoa, Solomon Islands and Marshall Islands, and during El Niño in the Cook Islands, Fiji and Kiribati. The short term signal was strongest in Fiji, Tonga, Cook Islands and Samoa, particularly during the cyclone season.
- The synthetic cyclone modelling showed that the north-western coastlines of Viti Levu and Vanua Levu experienced the highest storm surges because they face the most common direction of approach for tropical cyclones. The 1 in 100 year storm surge heights on northwest coasts were found to be around twice the values at locations in the southwest. Due to differences in tropical cyclone paths and frequencies, the northern island was slightly more at risk of storm surges during El Niño years.

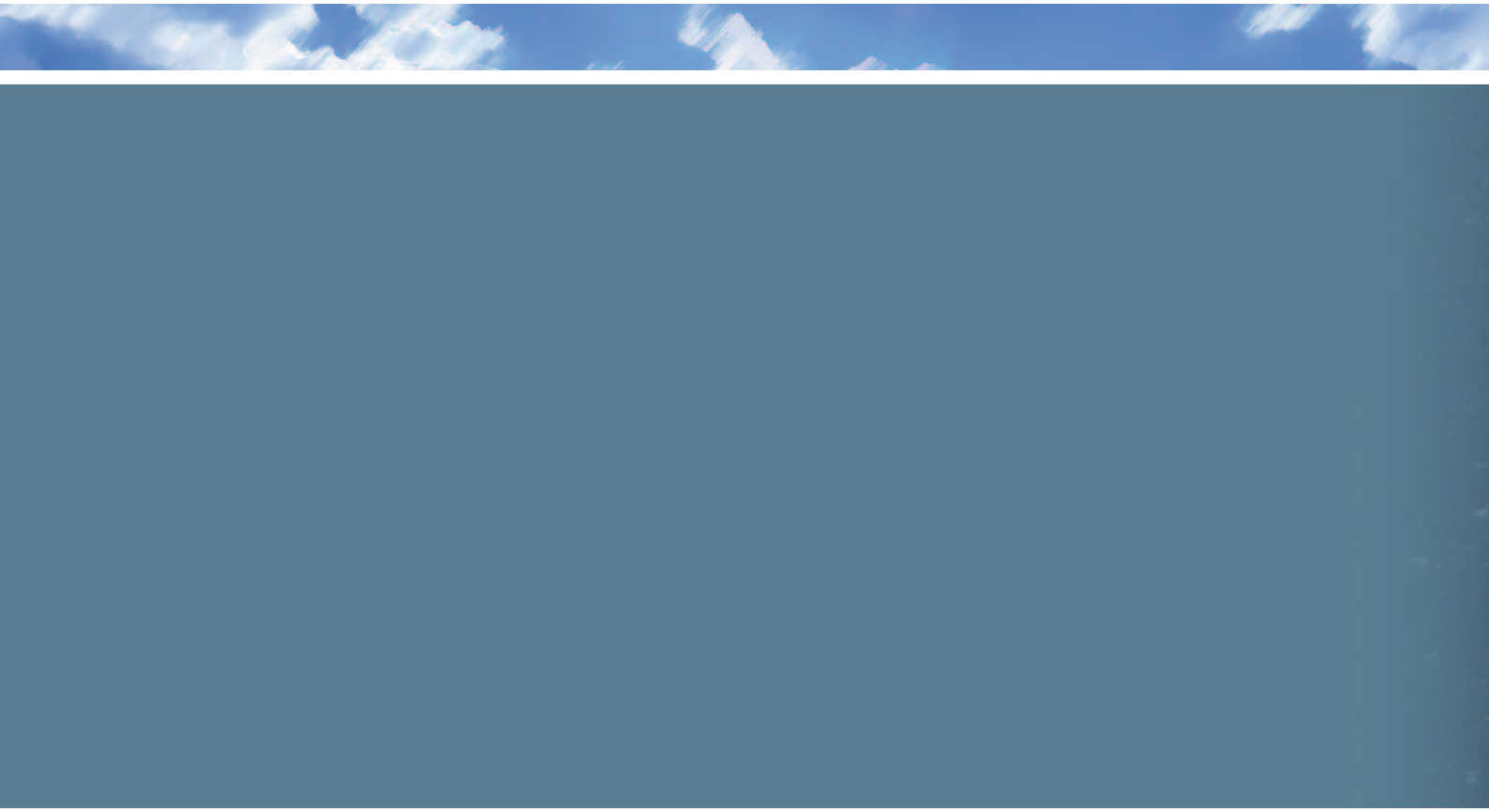
Papers: Published and in press

McInnes, K.L., O'Grady, J.G., Walsh, K.J.E. and Colberg, F. 2011: Progress towards quantifying storm surge risk in Fiji due to climate variability and change J. Coastal Res. SI64. 1121-1124.

Walsh, K.J.E., McInnes, K.L. and McBride, J.L. 2011: Climate change impacts on tropical cyclones and extreme sea levels in the South Pacific – a regional assessment. Global and Planetary Change, doi:10.1016/j.gloplacha.2011.10.006.

Papers: Under preparation and submitted

Hoeke, R., McInnes, K.L. 2012: Extreme water level climatologies for Pacific Islands (in prep).



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